MODERN TUNNEL PRACTICE

ILLUSTRATED BY EXAMPLES TAKEN FROM ACTUAL RECENT WORK IN THE UNITED STATES AND IN FOREIGN COUNTRIES

BY

DAVID McNEELY STAUFFER

Member American Society of Civil Engineers; Member Institution of Civil Engineers; Vice-President Engineering News Publishing Co.

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PREFACE

The practice of tunneling, in many of its important features, has been radically changed within a comparatively short period by the introduction of high explosives, by the use of machine drills, by special appliances for handling the debris or protecting the roof of the tunnel, and by the employment of electric power and light. As a consequence of these innovations, much that was useful to the engineer and to the contractor in the older works upon tunneling is now out of date; and with this in view, the present work has been compiled.

As to methods to be pursued, it is unnecessary to tell the practicing engineer that each piece of tunnel work is practically a problem calling for individual solution. No broad rules can be laid down which will cover all possible conditions, though some general principles for guidance can be formulated. In the arrangement of this work, therefore, especial effort has been made to present modern practice in tunneling under as many varying conditions as possible, and to clearly and concisely describe the methods actually adopted in carrying on the work under certain controlling conditions.

The material used is very largely taken from the detailed descriptions of modern tunnel work as these are found in the pages of technical journals and in the proceedings of engineering societies, supplementing this by the personal experience of engineers and contractors who do not usually make a formal record of this experience. Illustration is very freely employed, because it frequently tells more than can be expressed in the text alone. And in every case the description of any especial method is prefaced by a brief statement of the physical conditions which called for some particular treatment. It is believed that the examples selected cover a wide range of practice. As

only typical modern cases have been cited, no attempt has been made to include every important tunnel. The field is too wide, in fact, to be intelligently covered in any one book.

The instrumental work, or surveying, connected with tunneling, differs very little from that common to all larger public works, and as many special textbooks are devoted solely to the use and care of engineering instruments, what is here said upon that subject is intended simply as a general statement of the processes involved and of their sequence.

The composition, nature and use of modern explosives have been treated at considerable length; but here again, much has been left out that was considered as having little or no useful bearing upon modern practice in tunnel building.

The writer acknowledges his indebtedness for some of the material here used, to Mr. Drinker's monumental work upon tunneling, published in 1878. And he has also freely used the comprehensive handbook upon explosives, written by Mr. M. Eisler, and the excellent manual on the care and handling of explosives prepared by Prof. Courtenay De Kalb, for the Ontario Bureau of Mines.

D. McN. Stauffer.

New York City, Dec. 1, 1905.

CHAPTER I

TUNNEL LOCATION AND SURVEYING

Selection of a tunnel route—General rules for location—Geological considerations—Alignment of tunnels—Station points—The Cascade tunnel—Carrying the center-line down a shaft—Tunnel-targets.

The route selected for a tunnel depends somewhat upon the end in view. If the tunnel is intended to meet the demands of modern rapid-transit in a great city, or if it is proposed to connect two parts of a city separated by a waterway, the lines of traffic as indicated by existing streets will very generally control the location. In such cases the engineer has a comparatively narrow choice of routes; and he must deal with the problem as he finds it.

Railway tunnels, other than the rapid-transit tunnels referred to, have for their chief objects the reduction of grades and the shortening of distance between given points separated by a dividing mountain or ridge, or a projecting spur. In such cases the surface conditions may be so complex as to admit of several distinct tunnel lines between the terminal points; and it is the business of the engineer to find the one line best adapted to the proposed traffic and the most economical in construction and operation.

No fixed laws can be laid down for the engineer that will cover every possible contingency of tunnel location. The experience of the locating engineer in similar work and his good judgment as based upon this experience can alone produce successful results.

There are, however, some general points that must be carefully weighed by the engineer as these are presented in his study of the actual topography of the country to be traversed.

A tunnel is always an expensive and troublesome piece of

construction; and it should be avoided if conditions of traffic and the economic operation of this traffic will warrant any other solution of the problem.

But it should not be forgotten that there are cases where a tunnel is safer and is really more economical in the end than an apparently cheaper open cut or a longer and curved line passing around some natural obstruction. In the case of the open cut, the material may show a tendency to slide, and the volume that ultimately may have to be removed, to provide a stable slope, may be so great as closely to approximate—if not exceed—the estimated cost of a tunnel. On the other hand, tunneling through ground of this description is expensive work; and the utmost care and experience are necessary in deciding upon the plan finally to be adopted. As the necessary slope in the sides of a cut can rarely be decided upon in advance, and as this slope is practically controlled by the stratification of the ground, the operated line in an open cut is subjected to positive danger from slides of earth or rock. In elevated and mountainous regions, subject to heavy snowfalls and resulting avalanches, or falls of rock loosened by frost, the open cut is especially objectionable, and the more expensive tunnel may be advisable, and really cheaper in the end.

In a winding valley with relatively sharp curves a tunnel or a series of tunnels will usually reduce distance and permit of a better location and more economical operation than a curved surface line. And in such cases it is often good practice to build a tunnel rather than to erect and maintain the bridges otherwise necessary at stream crossings. Careful surveys and a close study of alternative plans can alone decide these points.

In the suburbs of large cities a tunnel may, again, be a cheaper structure than a sunken way, with its many street bridges, or than an elevated structure occupying valuable land.

Geological Considerations in Tunnel Location.—The cost of a tunnel is largely measured by the character of the material penetrated. A careful study of the natural formation is therefore a necessary preliminary to any intelligent estimate of this cost, or even to any final location.

It is practically impossible to foretell with any degree of certainty just what material and what stratification may be found in the interior of a mountain. And that a geological forecast of this kind should have any value at all, this work should be entrusted only to a geologist of wide experience and good judgment; and even then the records of engineering are full of the mistakes of experts in this connection. In most cases borings made along the line of the work can alone be depended upon, though these borings may also deceive if read by the inexpert.

There are, however, surface indications that have some value in establishing the general character of the work to be performed. If the rock, in its outcroppings, is hard and relatively little affected by atmospheric conditions, it may be classed as good and probably will stand well. If, on the other hand, this surface rock is seamy, or shows a tendency to disintegrate under the effect of moisture and frost, or if it contains pyrites, heavy timbering and troublesome and expensive work may be expected.

The general inclination of the strata, with reference to the tunnel section, and the frequency of seams in the rock, indicate to some extent the pressures or slips to be guarded against and the amount and kind of timbering necessary. The existence of bodies of water lying above the tunnel level, taken in connection with any prevailing direction in the rock seams, affords some indication of the amount of water to be dealt with and the pressure with which it will escape into the workings. In the case of a deep and long tunnel, however, it is generally impossible to trace underground conditions with any degree of certainty; and the safest course is to generally guard against the unexpected.

Among the treacherous and difficult materials encountered in tunneling the following are probably the worst: Laminated wet clay that may exert enormous pressures by swelling; shales liable to swell and to disintegrate upon exposure to air or water; small, dry, loose sand or gravel, that will run like a fluid through a relatively small opening and bring unequal pressures upon the timbering, and water-bearing sand. Each one of these

materials demands special treatment, expensive timbering and heavy masonry lining, and patience. How engineers have met these problems in actual practice will be seen in following chapters of this work.

Tunnel Surveying.—When the general location of a tunnel route has been definitely fixed, the points to be next considered are: The exact alignment, the gradients to be adopted, the final length of the tunnel, and the establishment of permanent stations marking the line.

Wherever possible the alignment should be a tangent. A straight line is the shortest line between two points, and it is most easily and certainly carried through the workings. In very mountainous regions, however, and especially where a line has to follow a deep and crooked gorge with precipitous sides, curvature in the tunnel or tunnels may be absolutely unavoidable. And in great tunnels, like the St. Gothard, for example, spiral and looped tunnels are employed for the purpose of obtaining distance and consequently easier grades, in a line run between two points that are horizontally near each other, but vary greatly in relative elevations.

Unless the grade is a continuous one, which is rarely the case, the summit or highest point in the tunnel should be as near to the center of the tunnel as possible. By this disposition of the summit natural drainage is secured toward the two portals. Except in very long tunnels, or in tunnels having a comparatively small depth of ground overlying them, intermediate shafts have been largely eliminated by the introduction of high explosives and modern machinery, which vastly shorten the time of completion and do away with the necessity of increasing the number of working faces by multiplying shafts. This absence of shafts has a direct effect upon the drainage problem and decreases pumping.

The final length of a tunnel is generally fixed by the most economical limits of the open-cut approaches; and this length cannot be definitely known until the approaches are actually completed.

The instrumental work of a tunnel survey is largely that of

any other important survey; the chief requisites being first-class instruments and experience, care and patience on the part of the observers.

Assuming that the line is a tangent, the problem to be solved is the laying down of this line across the mountain to be pierced, extending this line beyond both portals and then permanently marking the established line in such manner that it can be produced into each portal. If the tunnel is surmounted by a single peak or ridge, from which both ends of the tunnel can be seen, the problem is presented in its simplest form. The preliminary line, or a special survey, will approximately fix the summit point; but this point must then be tested and adjusted by a patient series of sights and reversed sights taken upon stations assumed to mark the ends of the line, and the necessary shifting laterally of the transit instrument. With the mean of many sights finally adopted as indicating the correct line, a permanent sighting station is fixed upon this summit which serves as a forward sight for each portal station, in prolonging the line into the tunnel as work progresses.

If the tunnel is very long, or the summit of the mountain is broken into several ridges and the ends of the tunnel cannot be seen from a single middle station, then triangulation becomes necessary, with all the skill and careful work that this process implies. For shorter tunnels any standard work on surveying will indicate the triangulation methods employed; and for the greater tunnels, like those penetrating the Alps, the reader is referred to the history of these tunnels.

In whatever manner the main station points have been established, they must be repeatedly and carefully tested under all atmospheric conditions; in winter and in summer, and by day and by night. Experience proves that the best time for sighting is about sunrise, before the heat of the sun can cause atmospheric disturbances. A plummet-lamp, used on a clear, calm night, is usually found to give more accurate results than other forms of targets sighted upon in the daytime.

The permanent station points should be very solidly constructed, with stone foundations laid deep enough to be unaf-

fected by frost. And in the case of the summit station, sighting conditions may demand that the line point be transferred to the top of a strong and rigidly braced wooden structure, surmounted by a platform about 8 feet square.

Especial care must be exercised in locating and in preserving the portal stations from all danger of interference; for it is from these stations that the line is prolonged into the tunnel. Workmen are proverbially careless in the matter of preserving "points," either inside or outside of the tunnel, and it remains to the engineer to devise means of minimizing danger in this connection.

To diminish some of the difficulties encountered in preserv-

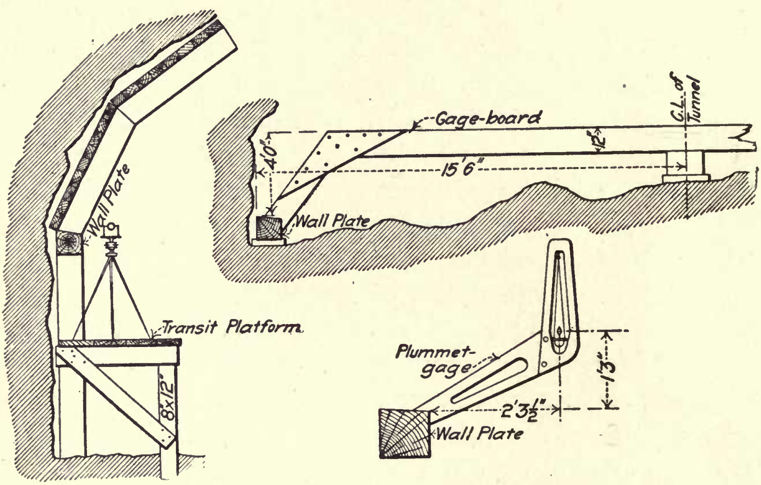


FIG. 1.—Dunham Method of Tunnel Alignment.

ing the tunnel points, Mr. H. F. Dunham, M. Am. Soc. C. E., suggests the following mode of procedure.* In the first place, he removes his line from the center of the tunnel approach, where it is always in trouble, to one side of this approach. At a point about 50 feet from the tunnel portal, and against one side of the approach, he built a strong timber platform, supported by 8 x 12-inch posts set 3 feet into the rock. As the alignment

*Trans. Am. Soc. C. E.; Vol. XXVII, p. 453.

of a timbered tunnel is generally established by the lining-up of the wall-plates, the level of this platform was such that when an ordinary wye-level was set upon it the line of sight would strike a little above and inside the line of the wall-plates on that side of the tunnel. To enable the instrument to be quickly set in position small holes were made in the platform and protected by iron washers, marking the position of the three legs.

The distance between the center-line of the tunnel and the center-line of the instrument and the height of the instrument were carefully measured and noted; and these measurements were used in fixing a permanent target back of the portal and about 1,000 feet away. A gage-board of convenient form was then made, which would rest upon the corner of the wall-plate and also support a plummet-lamp. A larger board was provided that would span one-half the distance between the wall-plates; and in both gages the parts liable to wear were protected with iron.

The work of alignment was then conducted as follows: The instrument was set upon the platform, sighted upon the rear target, and securely clamped. The level was next carefully reversed in the wyes and used to line-in the plummet-lamp attached to the smaller gage-board, this board being held upon the wall-plate and the plate moved laterally, or raised and lowered, as the rodman might direct. With the wall-plate on one side of the tunnel fixed in place, the longer gage, with a spirit-level placed upon it, was employed in determining the position of the opposite wall-plate. To carry out this method a space 2 feet wide and 2 feet high must be kept cleared of all timber and broken stone across the floor of the heading.

Mr. Dunham, in describing this method, says that the necessary instrumental work can be done in one-fourth the time demanded in the older methods. The work performed by the level was checked up at intervals by running-in the center line with a transit. Under conditions under which men could work, the plummet-lamp could be sighted upon up to about 1,000 feet.

The Cascade Tunnel.—The following account of instru-

mental work done at the Cascade tunnel of the Great Northern Railway is condensed from an article written by the then chief engineer, John F. Stevens, M. Am. Soc. C. E.,* now chief engineer of the Panama Canal. As shown by the map presented, we here have in concrete form the economic gain of a tunnel over surface crossing of this same mountain, the surface line in this case, however, being represented by a temporary switchback used during the construction of the tunnel. This switchback represents the cheapest location across the ridge. To have flattened out the curves and to have reduced the gradients by

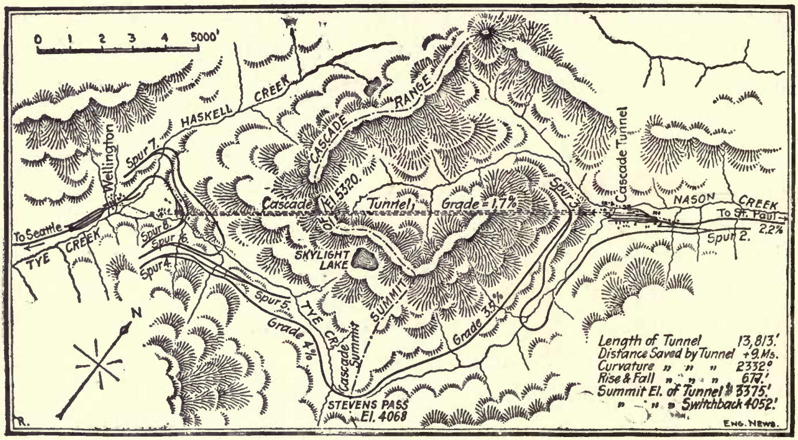


FIG. 2.—Map, Showing Cascade Tunnel Location and the Temporary Switchback.

the necessary loops would have made the contrast still more striking between the surface and the tunnel lines.

As compared with the switchback, the construction of the tunnel saved 9 miles in distance, 2,332° of curvature, and 700 feet in rise and fall. Aside from these considerations of construction and decrease in time of crossing the summit, the building of this straight tunnel vastly decreased the maintenance-of-way expenses. Mr. Stevens points out that the snowfall in the Cascade Range is excessive, and in the winter of 1897-98 the aggregate snowfall at the summit of the switch-

*Engineering News, Jan. 10, 1901.

back was 140 feet, with 20 feet of snow on the level at times. The removal of this snow from the switchback tracks was very difficult and costly; and this factor of expense, and also the delay in traffic, were the determining factors in deciding upon the tunnel line.

The accompanying map shows that the mountain overlying the tunnel line has two peaks, the western or highest peak having an elevation of 2,150 feet above the portal at that end, and the eastern peak lying 1,750 feet above the east portal. By many trials transit points were established on each of these peaks, each commanding the other, as well as points just outside the two portals. These points were carefully checked by observations, repeated many times under the most favorable atmospheric conditions.

Timber towers 16 feet high were erected at each of these summit stations, and in the center of each tower gas-pipe targets were secured; each pipe was 2 inches in diameter and 20 feet long, so as to be seen above the deep snow; and whenever the opportunity offered these pipe targets were tested by dropping a plumb-line through them to a tack below them. Intermediate fore-sights were also located on the mountainside, to be used when the summit targets were obscured by clouds. At each portal permanent transit stations were made by building a strong elevated structure, spanning the working tracks and roofed over.

The length of the tunnel was obtained by direct measurements, this method being preferred to any system of triangulation possible on that ground. Measurements were made with a 400-foot steel tape, on measurement points previously established as nearly 400 feet apart as the nature of the ground would permit. These "points" were located on high stumps, on braces nailed to trees, or on plugs driven into holes drilled in the rock; the elevations of these points were carefully taken with the level. In measuring, the tension of the steel tape was regulated by a spring balance, and the temperature was noted at each end of the steel tape. Work was usually done on cloudy days and when there was little wind; and

as a preliminary a base-line had been laid out with a 100-foot standard tape, and with this the proper tension to apply to the 400-foot tape was fixed, 62° Fahr. being assumed as the normal temperature. From the slope measurements, corrected for temperature and vertical measurements, the horizontal distances were calculated.

Inside the tunnel the measurements were carried along the plumb-posts, and after the concrete lining had been completed each station was marked on plugs driven into holes drilled in the concrete. Bench-marks for the levelman were made in a similar manner.

In prolonging the center-line, transit sights were placed in the key-segment of the timber arch; and at intervals of about 800 feet platforms were erected at the elevation of the wall-plates, with two independent floors, one to support the transit, and the other to hold the observer. Electric lights, carefully centered, served as back-sights. By this arrangement of transit platforms the muck and concrete cars passed beneath them without interfering with the work of the engineering party.

Carrying a Center-line Down a Shaft.—While modern methods of tunnel-driving have eliminated shaft-work to a considerable extent, it is still necessary at times to transfer the center-line of a tunnel down a shaft, the difficulties of the problem increasing with the depth of the shaft.

To do this the center-line must be carried to the mouth of the shaft, and marked upon permanent station-points located on either side of the shaft and about 25 feet away from the shaft. While the shaft timbers themselves may now be used for the prolongation of the center-line, it is better to place these marks on solid supports near to, but independent of the shaft lining. With these shaft points fixed, two horizontal steel wires, about one-sixteenth inch apart, are stretched between the points, with the space between the wires coinciding with the center-line. These steel wires are usually kept tightly stretched by means of a small drum and ratchet.

To transfer to the bottom the line thus established over the mouth of the shaft, two wires of steel or copper, strong and as

small as possible, are passed between the horizontal wires and as far apart as the dimensions of the shaft will permit. To the bottom of these wires two plummets, weighing 15 pounds or more, are attached. If the shaft is deep the suspended wires are liable to disturbance by air currents, or by falling water, and in such cases the wires are often protected by passing them through light pine boxes, about 6 inches square, attached to the floor of the shaft. To check oscillation in the plummet-wires the plummets themselves are allowed to swing in buckets of water, oil, or some other fluid, placed in the bottom of the shaft.

The final operation is to determine, from the position of the two plummet-wires at the bottom of the shaft, the correct center-line; to permanently mark this center-line at the bottom, and to prolong this line into the tunnel in both directions as the headings progress. As the base-line thus transferred is necessarily very short, an exceedingly small error is rapidly multiplied in the prolongation, and the utmost care and patience must be observed throughout.

To fix the line below, two beams are securely fastened just above the roof of the tunnel and close to the two plummet-wires. To these beams brass scales are attached, and the oscillation of the wires before these scales is patiently watched and noted. The mean of hundreds of these oscillations is finally assumed as marking the true line, and this mean is marked upon the scales. From these latter marks two other plummets are suspended, and from these thin wires the tunnel line is prolonged by a transit, in the usual manner of shifting and checking. If the tunnel has a firm rock roof, the line of prolongation is marked by driving plugs into holes drilled in the roof, and from small hooks in these plugs plummet-lamps are suspended for sights.

The device shown in Fig. 3 is the scale used in marking the center-line at the bottom of the shaft on the Central Park tunnel of the New York Rapid Transit Railway. In this case the distance between the wires was only 7.9 feet; and fine piano wire was used for suspending 25-pound plummets, hanging freely in a tub of water. The brass bars were fixed in the

roof as shown, and the center part was graduated in tenths and hundredths of a foot. A vernier, reading to two-thousandths, slides over the top of the bar, with its zero intersected by the plummet-line.

One of the most notable cases of alignment transfer down a deep shaft is the work of this class done at the Hoosac tunnel. This shaft was 1,030 feet deep, and it was encumbered by sixty-four separate floors. The base available at the bottom of the shaft was 23 feet long, and to this the line was transferred from the surface practically in the manner described above. But from this base of 23 feet the engineers prolonged the cen-

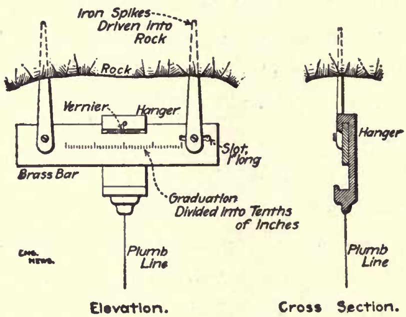


FIG. 3.—Device Used for Marking the Center-line of a Tunnel, at the Foot of a Shaft.

ter-line 1,563 feet east and 2,056 feet west, with errors of alignment of only 5-16 inch and 9-16 inch respectively.

In this Hoosac tunnel the ordinary distant target was a dark-lantern with a small parabolic reflector and a panel of ground glass on the side facing the transit. In front of this panel the plummet was hung, this being sometimes a $\frac{1}{4}$-inch turned, black rod forming part of the suspending line. At other times a brass plate was employed; this plate was 4 inches wide, and had in it a vertical slit from $\frac{1}{4}$ to $\frac{1}{2}$ inch wide, the slit coinciding with the plumb-line. With good air in the tunnel these sights were plainly seen at distances of 1,000 to 1,500 feet.

At the present time electric lights are largely used in tunnels for sighting purposes, and this light is so penetrating that

it can be successfully used, even under somewhat foggy conditions. Kerosene lamps, which are easily handled by unskilled labor, also furnish excellent results; and in geodetic work an 8-inch reflector attached to a lamp of this kind enabled the light to be bisected at a distance of forty miles.

CHAPTER II

EXPLOSIVES

Gunpowder; its composition, reaction, measure of force, temperature, etc. —Nitro-glycerine; its composition, action, and original method of use—Nitro-gelatine, as employed in blasting operations—Dynamite; its action, etc.—Lithofracteur, Forcite, Atlas powder, Hercules powder, Judson powder, Joveite—The Sprengel class of explosives—Safety or time fuses—The primer—Electric firing—Cautions to be observed in firing high explosives—The handling and storing of explosives—Frozen dynamite and its treatment—Powder magazines.

A variety of explosive compounds are now employed in blasting operations, though the so-called modern high explosives have largely supplanted the old black powder for all tunneling work. But for purpose of information, the various explosive agents coming within the scope of this work are here briefly described.

Gunpowder.—This oldest of explosives is made of various percentages of nitre, sulphur and charcoal, according to the purpose intended. For military use, the proportions adopted by the War Department of the United States are: 75 parts nitre, 10 parts sulphur, and 15 parts charcoal. But, while this is the standard composition, for certain blasting operations, as in coal mining—where a heaving, or rending, rather than a shattering effect is desirable—a weaker composition is frequently employed, the proportions being as low as 65 parts nitre, 15 parts sulphur, and 20 parts charcoal.

Good gunpowder should show hard, angular grains which do not soil the fingers, and the grains should have a perfectly uniform dark-gray color. If the color is bluish or jet-black, the powder contains an excess either of charcoal or of water. The appearance of bluish-white specks indicates that the nitre has effervesced in drying, or that the powder has absorbed suffi-

cient water to partially dissolve the nitre. In either case the mixture is no longer uniform. When gunpowder is new it should be free from dust, and it should leave no residuum or stain when flashed on a copper or porcelain plate.

Probably the best summary of the results of the primary and secondary reactions that occur in the explosion of gunpowder is that given by Dr. Debus, as follows:

"The combustion of gunpowder consists of two distinct stages: a process of oxidation, which is finished in a very short time, occupying only a very small fraction of a second, and causing the explosion, and during which potassium carbonate and sulphate, carbonic acid, and some carbonic oxide and nitrogen are produced; and a process of reduction, which succeeds the process of oxidation and requires a comparatively long time for its completion.

"As the oxygen of the saltpeter is not sufficient to oxidize all the carbon to carbonic acid, and all the sulphur to sulphuric acid, a portion of the carbon and a portion of the sulphur are left free at the end of the process of oxidation. The carbon so left reduces, during the second stage of the combustion, potassic sulphate, and the free sulphur decomposes potassic carbonate. Hydrogen and marsh-gas, which are formed by the action of heat upon charcoal, likewise reduce potassic sulphate, and some hydrogen combines with sulphur and forms sulphureted hydrogen."

The force of the blasting powder is measured either by the pressure of the gases given off or by the work done. The pressure of the gases depends upon the nature, volume and temperature; while the work performed depends upon the amount of heat given off. It is practically impossible, however, to exactly determine the potential energy of the explosion of gunpowder, owing to the fact that its rate of explosion is slow as compared with modern compounds; and as nearly all rock is more or less seamy or loose, the gas escapes at every crack, and with this gas we also lose heat that would otherwise perform work.

For these reasons the force resulting from the explosion of gunpowder cannot be even closely determined. Various authorities figure it from 15,000 pounds per square inch in loose rock, to about 200,000 pounds per square inch in the case of a modern type of gun, carefully loaded with the best and strongest powder.

Sir Frederick A. Abel is quoted as stating that gunpowder yields upon explosion 43% by weight of permanent gases, and 57% of matter which is solid at ordinary temperatures; but part of the latter may exist as vapor when the powder is exploded under pressure. At 0° Cent., and ordinary barometric pressure, the permanent gases generated by gunpowder occupy about 280 times the volume of the original powder. The temperature of the explosion is about 2,000° Cent., and these gases consequently exert a pressure, when developed in a confined space, which amounts to 6,400 atmospheres, or about 42 tons per square inch, if the powder completely fills the space in which it is exploded. Sir Frederick concludes that the total theoretic work which gunpowder is capable of performing, in expanding indefinitely, is about 486 foot-tons per pound of powder.

Nitroglycerine.—Nitroglycerine was discovered by Sobrero, in 1847, and, generally speaking, it is the product of the action of concentrated nitric acid upon glycerine, though the processes of manufacture vary.

At ordinary temperatures nitroglycerine is an oily liquid, clear and colorless, or yellowish; it refracts light, has a sweetish and burning taste, is without odor, and has a specific gravity of 1.6. At lower temperatures it becomes solid. It is insoluble in water, but dissolves easily in ether, wood spirit, benzol, chloroform, and hot alcohol. When taken into the human system it causes vertigo, weakening of sight, stupor, and pains in the cardiac region; and in larger doses it acts like strychnine, over ten grains being fatal. Even mere contact with the skin produces serious symptoms, though workmen get used to it in time.

Pure nitroglycerine does not decompose spontaneously at ordinary temperatures; it may be gradually heated to 100° Cent. without explosion, but it is then very sensitive to slight shocks. At 185° Cent., Champion says that it evaporates, boiling and evolving red fumes; at 217° Cent. it burns briskly, and at 257° Cent. it detonates with violence.

Alfred Nobel, the discoverer of dynamite, figures that one

volume of nitroglycerine disengages 1,298 volumes oi gas at 100° Cent. at ordinary barometric pressure; Dr. List estimates the bulk of the liberated gas at 1,505 volumes. At the lowest estimate, however, nitroglycerine evolves nearly six times as much gas as gunpowder at 100° Cent. But, as a far higher degree of heat is produced by the instantaneous combustion of nitroglycerine, Nobel claims that this heat expands the bulk of the free gases to eight times the original 1,298 volumes, while the gas of gunpowder would not be trebled at the same temperature. According to volume, then, the explosive force of nitroglycerine compares with that of gunpowder as thirteeen to one.

Nitroglycerine cannot be detonated by the simple application to it of a flame or heated iron; in a thin sheet the liquid simply burns away like gunpowder. It is only when heated to 257° Cent. in a closed space, that the entire mass explodes. A sudden blow will evolve heat enough to explode it; but in this case only the portion of the liquid actually struck will detonate. If the nitroglycerine is frozen, however, a blow given to a part of the mass is at once transmitted to the remaining portion, and accidents occur from this cause. The sun's rays also transform nitroglycerine into a very unstable, easily exploded substance.

In practice, nitroglycerine is exploded by the detonation of an adjacent volume of gunpowder, guncotton, or fulminates; and this occurs whether the nitroglycerine is loose or under confinement.

As at first used in blasting operations, nitroglycerine was employed in conjunction with gunpowder. A tin cartridge tube was filled first with gunpowder, and then nitroglycerine was poured in. The tube was closed by a cork and placed in a bore-hole, made somewhat larger in diameter than the cartridge, and the annular space was filled with a coarse-grained gunpowder, which covered the cartridge about one inch in depth. A fuse was inserted, the bore-hole was tamped with sand, and then fired. Nobel, later, poured the nitroglycerine directly into the bore-hole, and exploded it by a special black-powder detonator and a fuse.

The efficiency of the new explosive was at once recognized, and a great demand for it arose. But the liquid explosive leaked away into seams, parts did not explode and lay hidden in pockets, that were later liable to detonation under the action of a drill. Many fatal accidents occurred, and the blowing up of ships at Colon and San Francisco, about 1866, stopped the transport of the new explosive. Attempts were made to render nitroglycerine non-explosive by adding methylic alcohol, that could be removed by shaking in water; but the invention of dynamite, a comparatively solid form of nitroglycerine, caused the liquid compound to be abandoned except for some special use, as in increasing the flow of sluggish oil wells, etc.

Nitrogelatine.—The first marked improvement on the liquid form of nitroglycerine was the invention, by Nobel, of nitrogelatine, or nitroglycerine solidified by means of guncotton collodion. This compound was a solid jelly, and its inventor claimed that it was very safe and highly suitable for every purpose to which a very powerful explosive could be applied. This explosive jelly was pressed into cartridges, and exploded either by a strong fuse or, preferably, by a powerful detonator charged with fulminate.

As described by Gen. Abbot, nitrogelatine No. 1, or blasting gelatine, contained 92% nitroglycerine and 8% nitro-cotton. It is straw-colored, quite elastic to the touch, has a density of 1.6, and it can be cut with a knife. It softens a little at a temperature of 122° to 140° Fahr., and when inflamed in the open it burns like dynamite, or dry compressed guncotton. Pure explosive gelatine, slowly heated, detonates at 400° Fahr. When mixed with 4 to 10% of camphor it simply burns without exploding at 570° to 600° Fahr., or the temperature at which gunpowder explodes.

Nitrogelatine was one time quite extensively used in blasting rock under water, and is still useful in military operations.

Dynamite.—In attempting to render nitroglycerine less dangerous and better adapted to the uses of the engineer, Alfred Nobel finally invented dynamite. This is simply a combination of nitroglycerine with some porous and more or less inert sub-

stance that will absorb and hold the liquid without leakage. Many materials were tried before Nobel adopted for this purpose kieselguhr, an infusorial earth, chiefly found in Hanover, and made up of very minute siliceous plant skeletons, that hold the liquid within their recesses. The great success attending the employment of this kieselguhr dynamite led to the invention of a number of nitroglycerine compounds, all having for their main purpose the substitution of the solid for the liquid form, and some adding other ingredients intended to render the compound either more powerful or safer.

The action and effect of dynamite proper are practically stated under the head of Nitroglycerine. Mr. M. Eissler, in his "Handbook on Modern Explosives," gives a useful table comparing the power which various explosives are capable of exercising, bulk for bulk. This table is of far greater importance in its application to blasting than any comparison of the relative power of explosive substances, weight for weight, and is as follows:

Power of Explosives, Bulk for Bulk.—

Nitroglycerine	100.0
Ammonia powder	80.0
Dynamite, No. 1, 75% nitroglycerine	74.0
Lithofracteur	53.0
Guncotton	60.0

Lithofracteur.—This compound is made of 55% nitroglycerine, 21% kieselguhr, 6% charcoal, 15% barium nitrate and carbonate of soda, or either of them, and 3% sulphur and manganese oxide, or either of them.

Forcite.—Forcite was invented by Capt. J. M. Lewin, of the Swedish army. It is a mixture of nitroglycerine with cellulose, the latter being gelatinized by heating in water under considerable pressure.

As manufactured in America and Belgium, forcite is a thin blasting gelatine, or nitro-cotton, incorporated with a mixture of nitrate of soda, coated with molten sulphur and wood tar.

To counteract the stickiness of the tar, 1% of wood pulp is added.

Atlas Powder.—This is a composition of nitroglycerine, wood fibre, nitrate of soda, and 2% to 3% of carbonate of magnesia. It is made in various grades, containing from 20% to 75% of nitroglycerine.

American Hercules Powder.—In the No. 1 grade of this powder the proportions and ingredients are stated to be 75% nitroglycerine, 20% carbonate of magnesia, 2.1% nitrate of soda, 1.05% chlorate of potash, 1% white sugar.

The carbonate of magnesia is here employed as the absorbent. The claim is made that the resultant fumes from explosion are not so bad in their effect upon the miners as those arising from dynamite. Mr. Eissler says that this advantage may be due to the presence of the alkaline absorbent, which gives off gases which contain no carbonic oxide.

Judson Powder.—In this powder, instead of absorbing the nitroglycerine, as in the case of dynamite, a thin film of 5% to 15% of nitroglycerine is used as a final operation to coat grains of non-absorbent and non-hygroscopic oxidizing salts. This process is carried out in various ways.

One example of the oxidizing salts mentioned by Eissler is made up, by weight, of 15 parts sulphur, 3 parts resin, 2 parts asphalt, 70 parts nitrate of soda, 10 parts anthracite coal. The sulphur, resin and asphalt are melted together and well stirred; and to this melted mixture are added the nitrate of soda and the coal, both pulverized and thoroughly dry. The mixture is then gently stirred until so cool that the grains cease to adhere together, and these grains are thoroughly varnished. The nitroglycerine is added when the explosive is to be used. This powder is extensively used, is cheap, and is more powerful than common mining powder, depending for its strength on the percentage of nitroglycerine.

Joveite.—This substitute for dynamite belongs to the picric-acid class of powders. It is made by melting crystals of solid nitronaphthaline and solid picric acid in a steam-jacketed kettle or mixer, after which solid nitrate of soda is added. The prod-

uct is a yellow, granular substance resembling sawdust or cornmeal. This product is sold either in the granulated state or is made up into cartridges, resembling outwardly "sticks" of dynamite.

Joveite is fired with a cap, either with a fuse or with an electric battery. If the cap, however, is not thrust into the end of the stick, but placed about $\frac{3}{4}$ of an inch away from it, the joveite will not explode. In a test held in 1903 one capped stick was placed within 2 inches of the other sticks lying around it, and fired. The capped stick exploded, but the others did not. As joveite contains no liquid in its original composition, it is a solid, and should not freeze any more than black powder. And as it is made at a high temperature, Charles E. Munroe, Ph.D., of Columbian University, states that it is not subject to changes of condition or alternating heat and cold. He says that the powder showed no change after being exposed in open boxes in a room for four years. Its makers also claim that the fumes of burnt joveite produce no ill effect upon the workmen. It can be used in wet holes or under water, though it should not be left there long enough for the nitrate of soda to leak out. This difficulty is overcome by its makers, by putting it into cloth-covered wrappers entirely impervious to water.

The explosive power of joveite, as compared with nitroglycerine powders, is not stated; but as tested in a steel mortar, is over three times stronger in projectile force than black powder. As made in three grades, joveite No. 1 is said to be equivalent to 20% dynamite; No. 2 is equivalent to 40% dynamite, and No. 3XX is the equivalent of 60% dynamite. Bulk for bulk, joveite weighs fully one-third less than most dynamites of equal grade. It was patented in 1894.

Sprengel Class of Explosives.—In 1873 Dr. Hermann Sprengel introduced a type of explosive which had for its characteristic feature the admixture of an oxidizing with a combustible agent, at the time or just before it was to be used, the separate constituents of the mixture being non-explosive.

Dr. Sprengel originally used substances one or all of which would be liquid, as liquids better assured a speedy and intimate

mixture. But it was found by experience that there was too much danger attending the mixture of liquids by ordinary workmen, and other substances were discovered which were safer and still retained the advantages of the Sprengel principle, so far as transportation and mixing were concerned.

Rack-a-Rock.—This is the most widely known of the Sprengel mixtures. Gen. Abbot says that the best results are secured when rack-a-rock is made of 79 parts of potassium chlorate and 21 parts of mono-nitrobenzene. These ingredients may be safely transported and stored separately. When required for use the chlorite cartridges are placed in a special wire basket and dipped into a vessel holding the liquid mono-nitrobenzene for three to six seconds, depending on the size of the cartridges. The cartridges are then allowed to drain, and in ten minutes they are ready for use.

According to Gen. Abbot, rack-a-rock has a specific gravity of 1.7, and is a compact solid. It requires a very powerful detonator to explode it, and it decrepitates with difficulty when hammered on an anvil. Gen. John Newton, Corps of Engineers, U. S. A., employed 240,399 pounds of this explosive in blowing up Flood Rock, in the East River, New York.

Hellhoffite.—This compound was invented in 1885 by Hellhoff and Gruson. It is made of approximately 47 parts of meta-di-nitrobenzene and 53 parts of nitric acid. On mixture it appears as a dark-brown liquid. If mixed, and not immediately wanted for use, the di-nitrobenzene can be recrystallized by gradually adding water to the mixture, the acid being wasted.

To develop the full force of this compound a detonator is required that is twice as powerful as that used with dynamite. It is more powerful than nitroglycerine in the ratio of 106 to 100; and it can be stored and transported with perfect safety. But it is a liquid; the acid is volatile and can only be stored in perfectly tight vessels; it cannot be used for submarine work, as water renders it completely inexplosive; and the acid acts injuriously on the copper casing of the detonators.

Other Sprengel Compounds.—Other explosives of this type are known as Oxonite, Plancastite, Romite, etc. But, while

their great power as explosive agents is undoubted, their practical value is greatly diminished by reason of the relatively high degree of intelligence required in their proper admixture; by the fact that they are liquids; by the serious objection made to the fumes of the exploded ingredients in confined places, and by the fact that they cannot be used under water. They may have value for military operations, as their proper manipulation would be thus generally assured.

Safety or Time Fuses.—The ordinary or Bickford fuse includes a core of meal-powder, tightly compressed and enclosed in a wrapper of spun yarn impregnated with a waterproof composition. These fuses are made in various forms, with "single" and "double" tape, etc., the thicker wrapping being employed in damp places.

In using any make of safety fuse it is well to carefully determine the rate of burning. This is simply done by attaching different lengths of fuse to blasting caps and noting the time necessary for the powder to explode the cap. With the rate of burning known, the miner can cut a sufficient length of fuse to allow him ample time to retire to a place of safety before the charge is exploded.

In capping a fuse, examine the cap carefully to see that no particle of the sawdust in which the caps are packed remains inside. Cut the end of the fuse cleanly and squarely, and insert it in the cap until it is in close contact with the upper surface of the fulminate. The fuse must fit the cap snugly. If the fuse is too large, pare it down; if it is too small, wrap it with paper until it fits snugly. When this is all done the free end of the cap is tightly crimped to the fuse, so that it cannot be detached. If the charge to be fired is in a very damp place, or under water, the joining of the cap and the fuse should be made watertight by a coating of paraffine, tar, shellac, or some such substance.

Primer.—The primer is the cartridge to which the cap and fuse are attached. This primer is completed and the cap attached to the cartridge as follows: One end of the wrapper of the cartridge is opened—in the case of a dynamite cartridge—

and a smooth, round stick, slightly larger in diameter than the cap, is used to make a hole in the center of the cartridge. In this hole the cap is inserted; the cartridge is compressed by the hand so as to come in contact with the cap, and the end of the paper wrapper is then drawn around the fuse and tied tightly with a string. The cap should only have two-thirds of its length inserted into the cartridge; otherwise, the burning fuse might set fire to the cartridge before igniting the fulminate in the cap.

The completed primer is preferably placed in the center of the charge to be fired, and always in contact with the charge. The object of the blast in each individual case must determine the placing of the charge itself.

If only one cartridge is used in a hole, it is still advisable to use a primer, using for this purpose a piece of cartridge about two inches long, to which the fuse and cap are attached as described above.

Electric Firing.—The ordinary safety fuse has several serious disadvantages when employed to explode dynamite cartridges. It is liable to "miss fire," and to "hang fire," the last of these being the cause of innumerable accidents. It is also impossible to secure simultaneous action in the explosion of several charges, and there is a consequent loss of effect in the explosion.

In using the electric system of firing dynamite cartridges, the electric cap is entirely buried in the primer-cartridge; and, instead of tying the paper wrapper around the fuse, the fuse wires are doubled back and fastened to the primer by two half-hitches.

Electric Fuse.—The so-called low, medium and high-tension electric fuses only differ essentially in the manner of igniting them. The low-tension type acts by the heating of a very fine wire, imbedded in a proper priming, and the uniting of insulated conductors. The medium and high-tension fuses are fired by the passage of the electric spark over a break in the metallic circuit, this spark igniting a suitable priming.

Each electric fuse has two insulated conductors, a plug to receive and firmly hold the ends of the conductors near

to, but not touching each other; a small, sensitive priming properly arranged at the plug for firing, and a metallic cup or cap, usually containing fulminating mercury, representing the detonating charge. The so-called fuse-wires, extending out from the cap, must always be well insulated, and should not be less than two feet long.

Connecting or Lead Wires.—These two wires conduct the electric current from the igniting apparatus to the primer-cartridge. One of these wires conducts the electricity to the cap, and is known as the "conducting wire"; the other completes the circuit back to the igniter, and is known as the "return wire."

These wires should both be well insulated, for should bare wires touch each other or the ground a "short circuit" may be formed and the firing of the charge prevented. Bare wires can be used in special cases by placing them on poles and insulators. The best connecting wires are made of perfectly clean copper wire covered with india rubber insulation. For short distances wires may be insulated with paraffined cotton yarn, and these answer fairly well.

Firing Apparatus.—Various forms of igniting apparatus are employed in connection with the use of electric fuses. But the favorite machine—and one that is compact, strong and reliable—is the magneto-electric apparatus. This machine, as usually supplied, is contained in a wooden box about 16 x 8 x 5 inches, and weighs about eighteen pounds. Outwardly, this box shows a strap-handle, two brass binding-posts for the lead wires, and a central firing-bar working vertically. Without entering into the detail of the inner mechanism, it is sufficient to say that the novelty of this device lies in the method adopted for rotating a Siemens armature between the soft iron prolongations of the cores of an electro-magnet.

The brass firing-bar has a wooden handle at the top, and one side of the bar has rack teeth cut upon it, engaging in a loose pinion fitting over the armature spindle prolonged. When the bar is descending a clutch holds the spindle to the pinion, the pinion rotates, and a strong electrical current is produced; as

the bar ascends the clutch releases the spindle; there is no rotation, and action is thus restricted to the one downward movement of the bar. The purpose of this one-direction action is to avoid possible accidents in manipulating the machine.

To use this igniter, the ends of the two connecting wires are well cleaned, inserted in the two binding-posts on the box, and firmly held in position by the binding screws. The firing-bar is then pulled up to its full length, and when all is ready the bar is pushed down with a quick, uniform motion. Electricity is thus generated, transmitted by the wires to the cap, and the charge is exploded.

This machine may be temporarily disabled by two causes: (1) Dust or dirt may get between the platinum contact-points inside the box. To remedy this, remove the rear of the case and use a piece of fine emery-cloth on the contact-points. (2) The surface of the transformer or commutator may become tarnished. In this case open the rear of the box as before, and withdraw the firing-bar by first taking out a small pin at the bottom of the bar. The shelf holding the internal mechanism can now be partially withdrawn; the springs pressing upon the commutator and the spindle-yoke can be disconnected, and the face of the commutator can then be cleaned with emery-cloth.

Precautions to be Observed in Firing High Explosives.—In his lectures on explosives, delivered before the U. S. Artillery School, Lieut. W. Walke, U. S. A., gives some general advice upon the use of electricity in firing high explosives. This material is here condensed, with some additional matter added.

To reap the full benefit of this method especial attention must be paid to the preparation of the connecting wires. To prevent the ends of the leading wires from being constantly blown off, the "fuse wires" and the "connecting wires" should be connected by a coupling of two short wires. And, if practicable, the fuse wires should be long enough to extend at least six or eight inches outside of the bore-hole.

To connect the fuse and leading wires, pare off two to three inches of the insulating material from the ends of the wires and clean these ends with sand-paper. To join the wires, bend

back the ends of the wires to form hooks; hook the wires together, and then twist the ends of the wires closely and firmly around the hooks. Some old miners recommend as a better method the crossing of the ends of the wire, and then making about six close twists about the standing parts of the wires. In either case a close, tight twist is necessary, as a slack joint makes a bad connection.

In very damp ground this joint may be protected by slipping a small piece of thin rubber tubing over one wire before joining, and when the connection is made the tubing can be slipped over it and tightly tied at the ends.

A rule of great importance is: Never connect the fuse and the connecting wires until you are absolutely sure that one, at least, of the leading wires is disconnected from the igniting apparatus. The very last thing to be done before actually firing the charge is the connecting of the leading wires with the firing apparatus. All other connections must be made before this is done, and every precaution taken to see that the charge is ready for explosion.

All bare joints in connecting wires should be kept off the ground and out of the water; if this cannot be done, protect the joints as described above.

Special reels are made for handling the leading wires, and their use will be found to be economical.

By proper attention to all these details, Lieut. Walke says that it is possible to simultaneously fire fifteen charges in the same circuit.

Handling and Storing of Explosives.—In his "Handbook on Modern Explosives" Mr. M. Eissler gives some excellent advice in this direction, summarized as follows:

1. Put dynamite into close quarters, and hold it there by the most unyielding method of confinement at command. Let there be no vacancies about the charge of any kind or degree.

2. Always tamp if you can. But use a wooden rammer; never use an iron or steel bar with any explosive.

3. If you value your fingers, do not fool with the cap "to see what is in it."

4. The charge must fit and fill the bottom of the bore-hole, and be packed solid.

5. Never pick out a "miss fire" of powder or dynamite, but gently clear out the hole to within about eight inches of the old charge. Then place a fresh cartridge, or a piece of one, in the hole, and fill it up again as before. Fire this, and it will explode the original charge below.

6. Never attempt to roast, toast or bake frozen dynamite, and never put it into heated vessels or on boilers. The only absolutely safe method of thawing out frozen dynamite is to keep it in a room at summer heat and away from the fire until it is soft.

7. Never put a cap into a charge or a primer until you are ready to use it. And after the charge or primer is capped never let it leave your hands until it is put into the hole. Keep all caps away from the dynamite until the charge is to be fired. Invariably prepare your primer away from the explosive.

8. Never allow smoking, or other forms of fire, near the explosive. Powder and other explosives burn rapidly, especially when loose; and if any caps are incautiously left near by they may be fired and a dangerous explosion result.

9. Do not get nitroglycerine upon your fingers. It will be absorbed by the skin and cause headache, or worse.

10. For powder, use the best quality of double-tape fuse; it is always the cheapest and best in securing results. When you know that the ground is almost dry you can use single-tape fuse.

Frozen Dynamite.—When dynamite and other nitroglycerine compounds are frozen they can only be exploded by very strong primers; but the effect of the explosion is more violent than when exploded in a soft state.

As a rule, the frozen mass does not become uniformly hard throughout, because of slight variations in the proportions of nitroglycerine in different parts of the mixture, and partly because the external portion of the cartridge will be more thoroughly frozen than the interior, unless the exposure to cold is very prolonged. It may happen that partly frozen or wholly

unfrozen dynamite may be more or less completely enclosed in a strong crust of perfectly frozen and comparatively very cold dynamite. On exposure to considerable heat, rapidly applied, some part of the cartridge may be ignited and the unfrozen portion exploded. In such a case the hard, frozen dynamite practically acts as the metal envelope of a detonator; the explosive is confined and in a condition to exert extreme violence. The explosion of the unfrozen dynamite acts as a detonator or primer, and explodes the remainder of the dynamite.

For the reasons given above, Sir F. A. Abel points out the danger of assuming that because frozen dynamite is less sensitive to the effect of a blow, or to initiative detonation, than is the thawed material, it may be submitted to the action of heat, for the purpose of thawing it, without using special care.

Thawing Frozen Dynamite.—There are only two ways of safely thawing out frozen dynamite: (1) By placing the frozen

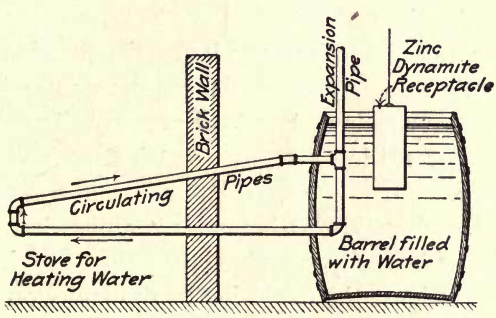


FIG. 4.—Dynamite Thawer: Hamilton Powder Co.

cartridges in a room heated to a summer heat by steam pipes, being careful to keep the explosive away from the pipes themselves. (2) By placing the cartridges in a suitably constructed vessel surrounded by water heated to 125° Fahr. The water should be heated separately and poured into the thawer. Sheet zinc is the best material for this thawer, though galvanized iron is largely used.

A form of thawer is sold which is built somewhat upon the model of a glue-pot. It has a hot-water receptacle, into which

fits another annular vessel for holding the cartridges. The water space between the inner vessel and the outer wall should be at least two inches wide. For thawing large quantities of dynamite at a time, the following plan is shown in Mr. De Kalb's "Manual," as recommended by the Hamilton Powder Company:

A barrel has fitted into it a circulating hot-water system of pipes, with an expansion pipe. This pipe system passes through a wall, and is heated by a stove. The barrel is filled with water, which is heated by the hot water circulating in the pipes, and kept hot. The frozen dynamite is put into the zinc or galvanized iron receptacle suspended in the barrel.

In using any kind of thawer, the only way of being sure that there are no accumulations of nitroglycerine in the thawer is to wash the thawer out after each thawing with a strong solution of washing soda, best applied warm. To the same end, all sawdust should be removed from the cartridges before they are put into the thawer.

As long as the dynamite feels lumpy in the cartridges it is not properly thawed. It should be uniformly pliable throughout. Aside from the danger in loading, partially thawed dynamite is less powerful in exploding, and it gives off particularly noxious fumes.

Dynamite-thawing House.—The dynamite-thawing house shown in Fig. 5 is one recommended by the commissioners appointed to investigate the explosion of dynamite on the Fourth Avenue section of the New York Rapid Transit Railway, on January 27, 1902. It is intended to hold 500 pounds of dynamite. The special feature of the design is the arrangement of the drawers immediately back of folding doors, leaving no space for a man to stand inside the magazine; and making it unnecessary to use any form of artificial light in handling the dynamite. An experimental house built on this plan cost $200.

Magazine.—In the storage of ordinary black powder, immunity from fire is a first consideration. As it is assumed in this work that the powder magazine is a more or less temporary structure, the more permanent forms of magazines are not here

discussed or described; and in general the form recommended is suitable for storing gunpowder or dynamite.

The Austrian law on the storage of all explosives requires that the structure used for this purpose should be as light as

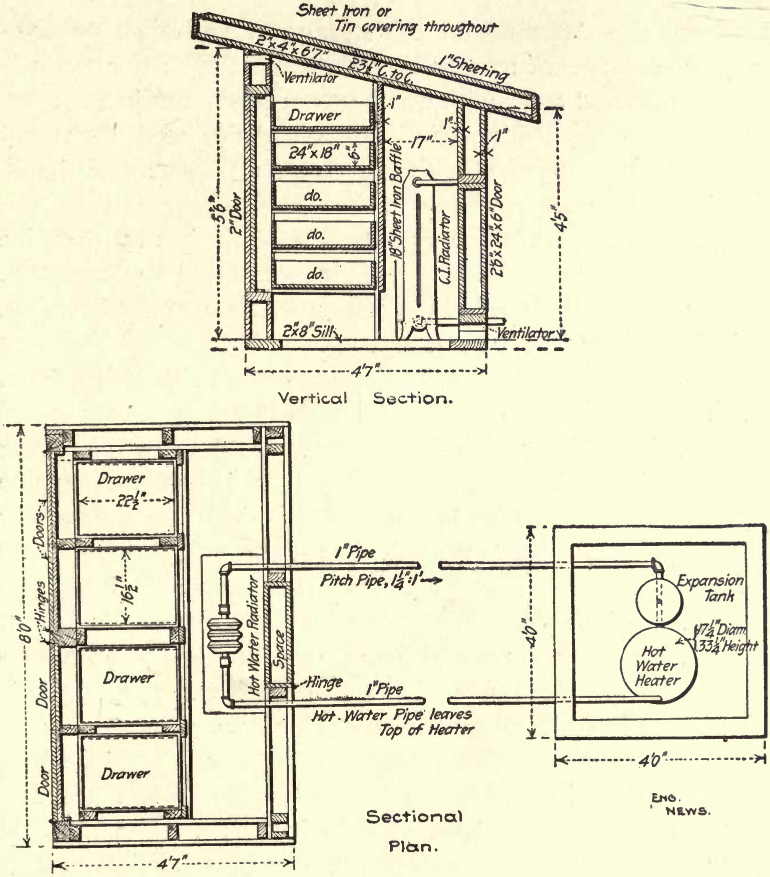


FIG. 5.—Dynamite-Thawing House.

possible. The purpose of this law is that, in case of explosion, the building may be completely disintegrated and no pieces of any size be thrown to a distance, thus reducing the radius of the danger zone to a minimum. In England the law demands

a more substantial structure, as a precaution against fire and burglars. But in a comparatively open country the light structure is preferable. Storage in a tunnel, cave, or other similar place should never be permitted, as such places are almost invariably damp, and any powder containing nitrates will be damaged.

A suitable structure for the storage of explosives on ordinary contract work may be described as follows: Use a 2 x 4-inch frame, and cover with weather boarding. Put in a tongue-and-grooved tight floor, blind-nailed, and the inside walls and ceiling may be sheathed with the same stuff. The roof should be A-form, and a covering of strong tar paper will make it tight. When there is danger from fire the roof and the outside walls may be covered with the lightest kind of steel shingles. A structure of this kind, 6 x 6 feet on the base, and 6 feet high, will hold about 216 kegs of powder.

As a further precaution, bottom ventilators should be put in, with the openings covered with wire to keep out vermin; and a hooded ventilator pipe should be extended from the ceiling through the roof. In a region where there is danger from rifle balls, the magazine may be built with a 6-inch space, enclosing fine, dry sand, extending upward as high as the kegs or cases of explosives are to be piled. Prof. Courtenay De Kalb, in a "Manual of Explosives," issued by the Ontario Bureau of Mines, says that, by actual experiment, the ball from a Lee-Metford rifle, at a range of twenty-four feet, only penetrated five inches into a sand protection of this type.

Storing.—In magazines, kegs of powder should be kept slightly inclined on suitable racks. Dynamite, when stored in tiers of cases, should have wooden battens between the tiers to insure ventilation and to lessen danger from friction.

No fulminates, or caps, and no loose coils of fuse should be stored in the same building with powder or dynamite.

The building should be kept very clean, and no fires or smoking permitted in or near it.

Gunpowder kegs should be rolled over every two or three days, to prevent caking. Cases of dynamite should be turned

over every two weeks. This tends to keep the dynamite homogeneous in composition and is economical.

No keg of powder or case of dynamite should be opened inside the magazine. This should be done in a distant and special small building, never containing at one time more than 200 pounds of an explosive. Keep kegs closed after taking out what powder is wanted. In the case of dynamite, unpack the cartridges and wipe off the sawdust, which usually contains some nitroglycerine. Carefully remove this sawdust and the boxes and burn them at some convenient distant point. Lay the cartridges on their sides on planed boards, and keep these boards clean at all times by removing oily stains with washing soda.

CHAPTER III

BLASTING

General principles to be observed in proportioning the depth and diameter of the holes to the work to be done—The line of least resistance—The location of bore-holes—The square and the V-shaped cut—The consumption of explosives—Method followed on the New York Subway—Testing the blasting properties of rock—Loading with black powder—Effect of nitro-glycerine fumes, and precautions to be observed—Hints on power-drilling—To prevent the crushing of shaft-timbers by flying rock.

No rigid rules can be laid down for the diameter and depth of holes, the direction these holes should take, the distance apart of holes, or the amount of the charge placed in each hole. The character of the material, the purpose of the blast, and a number of other and varying conditions will here control. Efficient work in blasting is a matter of experience and good judgment on the part of the miner, and this cannot be gained from books. But writers on this subject lay down some general and fundamental rules which must be observed in the interest of systematic, economical work.

Prof. De Kalb, in his "Manual," quoting from the works of Daw, Oscar Guttmann and others, lays down the following points of prime importance and general application:

1. The strength and quantity of the explosive should be properly proportioned to the cohesive strength or resistance of the rock.

2. The "burden," or line of least resistance (*i. e.*, the shortest line that can be drawn from the charge in the bore-hole to the outer free face of the rock), should bear a proper relation to the strength of the explosive and the resistance of the rock.

3. If the working face of the rock is so blasted as to leave two or more free faces, instead of one, for further blasts, the

power required to overcome the resistance of the rock will be reduced, and explosives can be economized.

4. A seam or fissure is a valuable aid in blasting if the hole is so located as to take advantage of this weakness; on the other hand the power of the explosive may be expended along such a seam without doing useful work, if the hole is improperly located.

5. Breaking to regular benches and faces is more economical than irregular breaking, because the condition of the rock can be more carefully observed, the subsequent bore-holes can be more intelligently placed, and it facilitates the setting up and handling of machine drills. It is also more convenient for hand-drilling.

6. Simultaneous firing of charges is more economical, in general, than single or series shots; for the adjacent charges assist each other, reducing the amount of explosive required and the total length of holes drilled for removing any given volume of rock.

7. Careful charging greatly increases the efficiency of the explosion.

8. In the case of high explosives a well prepared primer is the key to a successful detonation of the charge. Other things being equal, all efficiency depends on this.

9. The efficiency of all explosives, including high explosives, depends to a considerable extent upon the kind, length and degree of compactness of the tamping.

10. The object of blasting in a tunnel, quarry or mine is to rupture the rock so that it may be removed; hence only enough explosive should be used to do this. When fragments are thrown more than a few feet by a blast, it is generally an evidence that too large a charge was used for the length of the line of least resistance.

In the accompanying illustration, Fig. 6, *B N* is the bore-hole, *W L* is the shortest line measured from the center of the charge to the free face *A K*. *M O* is the charge, which should be about twelve times as long as the diameter of the bore at the bottom; *R S K* is the outline of the new face after blasting.

To obtain the best results the line of least resistance *W L* should be perpendicular to the bore-hole and shorter than the bore-hole. If it is not shorter the force of the explosion will exert itself in the direction of the bore-hole, and the result will be a crater, or a so-called "gun," with relatively little effect.

In very strong, compact rock the distance between holes, in simultaneous firing, should be at least twice the length of the line of least resistance; for average strong rock, $1\frac{1}{2}$ to 2 times;

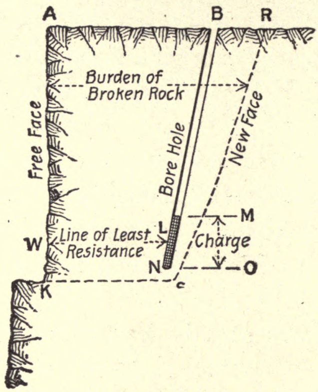


FIG. 6.—Blasting Nomenclature.

for moderately strong rock, 1 to $1\frac{1}{2}$ times, and for weak rock this distance should not exceed the length of the line of least resistance.

The lines of least resistance should be proportional in length to the diameter of the bore-holes, and Mr. Eissler gives the following table on this head:

	DIAMETER OF BORE HOLES.		
	1¼ in.	1½ in.	1¾ in.
	LINES OF LEAST RESISTANCE.		
No. 1.	3½ feet.	4 feet.	5 feet.
" 2.	3¾ "	5 "	6 "
" 3.	5 "	6 "	7 "

Mr. Eissler gives the corresponding depth of the bore-holes as: No. 1, equal to line of least resistance; No. 2, $1\frac{1}{2}$ times that length; No. 3, twice that length.

The economy in simultaneous firing varies with the strength of the rock; but it may be stated as an average, that there is a saving of about 25% in the explosives used. Under the best conditions there is also an economy of about 24% in the boring, depending on the distance apart of bore-holes.

Locating Bore-holes.—In tunnel driving or shaft-sinking, the first holes are drilled for the purpose of "unkeying" the face. If there is a persistent joint or seam, advantage should be taken of this seam, and the "key" may be thus broken out to the full depth of the cut with a minimum of explosive. In homogeneous rock a square of V-shaped center cut is generally adopted.

Square Center Cut.—Again quoting from DeKalb's "Manual," we have the plan and elevation of a square center cut (Fig. 7)

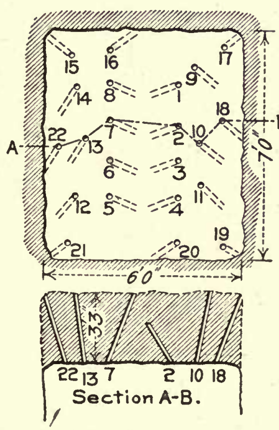


FIG. 7.—The Square Center-cut.

in a rock heading 7 feet high and 6 feet wide. The small circles in the plan indicate the commencement of the holes, and the parallel lines show their projection, or direction. The sectional elevation on the line *A B* shows this further, though hole No. 18 is only approximately accurate.

In this heading 20 holes have been bored reaching to a distance of 3 feet 3 inches from the face, which is the depth of the cut. Nos. 1, 2, 3, and 4 are the "unkeying" shots, converging

to a point; these holes preferably unite at the point, and they must be fired simultaneously. The remaining 16 holes are for the "enlarging" shots, to be fired in two or three successive volleys. The plan most economical of powder would be to fire 5, 7, 9, 11 in a second volley; 6, 8, 10, 12 in the third; 13, 14, 15, 16, 17, 18, 19, 20 in the fourth and last volley. Conditions, however, might make it more economical to use larger charges in 6, 8, 10, 12 and include them in the same volley with 5, 7, 9, 11. The last is one of the trimming-up shots; and to avoid irregularities in the rock it is essential to start the holes as close to the walls as possible, and to give them very little inclination.

V-shaped Center Cut.—In this form of cut (Fig. 8) there are fewer dry holes to be bored, and the "key" can be broken out

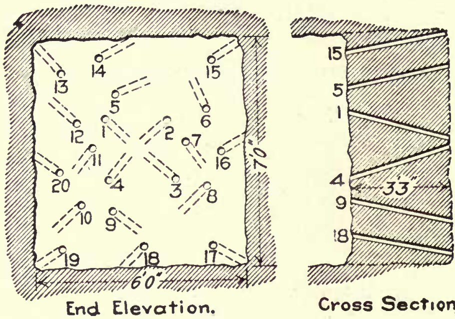


FIG. 8.—The V-Shaped Center-cut.

with smaller charges, as 1, 2, 3, 4 are short holes, with correspondingly short lines of resistance.

There are 22 holes in this heading. Nos. 1, 2, 3, 4 constitute the first volley, and provide shorter lines of resistance for the next shots—5, 6, 7, 8; holes 9, 10, 11, 12, 13, 14 make the third volley; and the trimming volley includes 15, 16, 17, 18, 19, 20, 21, 22.

In the case of both types of cut here described, the methods of procedure are given as suggestions for economical work under normal conditions. They must be suitably modified as these conditions vary.

An example of drilling and blasting methods is here taken

from the work performed on the New York Rapid Transit tunnel. The diagrams (Fig. 9) further illustrate the remarks already made on pointing and firing holes, and also note the usual nomenclature for the various holes.

The method of excavating the tunnel is substantially the single top-heading and bench method commonly employed in the United States. Both heading and bench, however, were unkeyed, or broken out by an opening and a trimming cut. Altogether 40 holes were drilled and blasted in opening up the full tunnel section. The approximate location and depth of these holes is shown in the diagrams, and with the work well under way, the sequence of firing is given in the table below:

Order of firing.	*Kind of holes, No.*	*Depth, feet.*	*Charge, pounds.*	*Climax, Dynamite, per cent.*
	BENCH HOLES.			
I.	7 grading.	3 to 5	50	40
II.	5 bench.	9.5	45	40
	HEADING HOLES.			
II.	6 trimming.	3 to 9	42	40
III.	8 center cut.	9	56	60
IV.	8 side.	8	48	40
V.	6 dry.	8	36	40

NOTE—All holes taper from 3 to 2¼ in. diameter.

Consumption of Explosives.—The amount of explosive required can only be determined by intelligent experiment under actual conditions present. But as a general guide one authority approximately estimates this consumption as follows:

For small blasts in open workings, $\frac{1}{4}$ to $\frac{1}{2}$ lb. of black powder, and 1-16 to $\frac{1}{8}$ lb. of dynamite, per ton of rock.

For large blasts, in open workings, $\frac{1}{6}$ to $\frac{1}{2}$ lb. of black powder, and $\frac{1}{2}$ to $\frac{1}{8}$ lb. of dynamite, per ton of rock.

For headings, tunnels and shafts, $\frac{1}{2}$ to 2 lbs. of dynamite per ton of rock.

In his "Handbook of Modern Explosives," Mr. Eissler gives a table of the quantity of explosives actually used in the course of tunneling work executed for the Glasgow Corporation Water Works. The average quantity of explosives, etc., used is given for each cubic yard in the several tunnels.

AVERAGE QUANTITY OF EXPLOSIVES, ETC., USED PER CUBIC YARD OF EXCAVATION; REDUCED FROM AMOUNT CONSUMED ON 1,400 LINEAL YARDS OF TUNNEL.

Tunnel.	*Dynamite, pounds.*	*Powder, pounds.*	*Fuse, hanks.*	*Detonators, boxes.*	*Candles, packets.*	*Naphtha, gall's.*	*Remarks.*
Ballewan, S.....	1.370	—	0.200	0.034	0.120	0.310	Very hard rock. Hand drilling. Day work.
Ballewan, N....	0.900	—	0.130	0.022	0.120	—	Good rock. Hand drilling. Sub-contract.
Dumgoyn, S....	1.270	—	0.200	0.027	0.210	—	Wet moderate rock. Hand drilling. Day work.
Dumgoyn, N....	1.970	—	0.210	0.025	0.100	0.200	Soft rock. Machines. Sub-contract.
Dumgoyn, N....	1.600	—	0.150	0.020	0.070	0.150	Hard rock. Machines. Sub-contract.
Sauchie	0.370	2.240	0.400	0.011	0.110	0.050	Dry red sandstone. Hand drilling. Sub-contract.
Lettre	1.163	0.308	0.180	0.029	0.150	0.120	Partly wet sandstone. Hand drilling. Day work.

Testing the Blasting Qualities of Rock.—Professor De Kalb, in his "Manual of Explosives," gives the following general directions for testing a rock that is to be broken; or, in other words, determining the most efficient and economical charge for the work to be performed. Select a homogeneous rock bench about 2 feet wide on top and 3 feet high. In this drill four or five

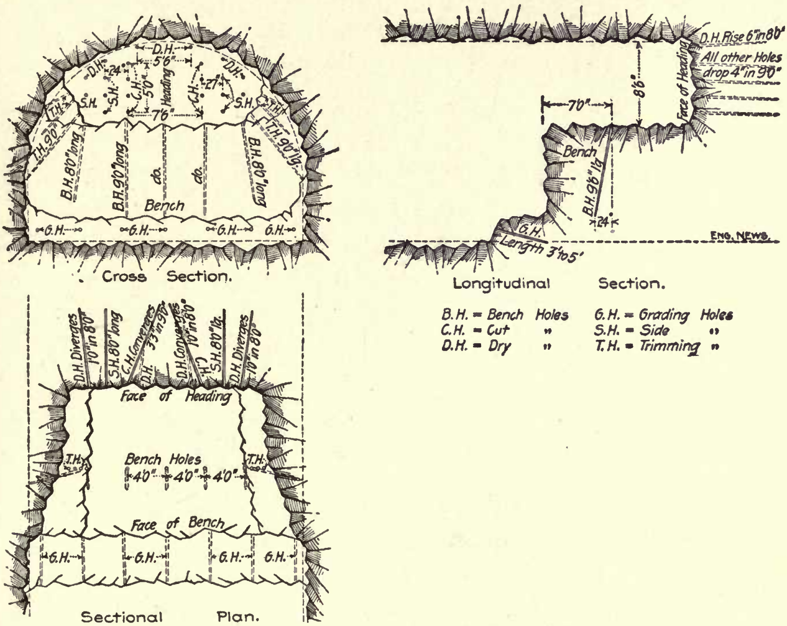


FIG. 9.—Drilling and Blasting Methods on the New York Rapid Transit Tunnel.

holes of the standard diameter, 3 feet deep, thus giving a line of least resistance equal in each case to 2 feet. The distance between these holes should be at least three times the length of the line of least resistance, so that one shot shall not influence another by opening up seams. Now charge the several holes with different weights of the explosive, beginning with a quantity so small as not to effect rupture, and increasing by regular amounts to a charge that will be more than sufficient. Select the blast which has produced the desired effect as the one determining the coefficient.

For example: If this hole were charged with $\frac{5}{8}$ lb. (0.625 lb.) of dynamite, then the rock coefficient is

$$\frac{0.625}{2^3\ (\doteq 8)} = 0.0781$$

The charge for future blasts is then found by multiplying the cube of the length in feet of the line of least resistance by this coefficient. Thus: If this line is $2\frac{3}{4}$ feet, the amount of dynamite necessary would be 2.75^3 ($= 20.797 \times 0.0781 =$ 1.624 lb. As the specific gravity of well compacted, high-grade dynamite is about 1.6, and as the bore-hole has a diameter of $1\frac{1}{2}$ inches, the charge will occupy a length of 1.25 feet in the hole. This is approximately correct also as to the length of charge in the bore-hole, which should have been $1.5 \times 12 = 18$ inches. Guttmann recommends that where there are more than two free faces the proper charge will be as follows:

For 3 free sides, $\frac{2}{3}$ of the calculated charge.
For 4 free sides, $\frac{1}{2}$ of the calculated charge.
For 5 free sides, 2-5 of the calculated charge.
For 6 free sides, $\frac{1}{2}$ of the calculated charge.

Loading with Black Powder.—The ordinary practice in loading a hole with black powder may be outlined as follows: Remove the sludge and dry out the hole by any proper material tied to the end of a long rod. Pour in the powder so that it does not touch the sides of the hole above the charge; for horizontal or inclined holes, the powder may be deposited in small paper bags, closely pressed home by a wooden rod. Special waterproof cartridges are supplied for wet holes. The fuse is now put in place, or tied to the last bag of powder, if bags are used.

Dry clay is next pressed over the charge, followed by 3 inches of ordinary wet clay pressed in firmly. After this further tamping may be rammed by tapping the end of the tamping stick with a hammer. Practice shows that the amount of tamping desirable is determined by the diameter of the hole and not by the volume of the charge. The least depths of tamping material admissible are: For a hole 2 inches in diameter,

7 inches of tamping; for a 2½-inch hole, 18 inches; for a 3-inch hole, 20 inches. The depth of tamping should always be somewhat in excess of these figures.

When Dynamite Is Used.—Mr. Eissler gives some useful general directions relating to the drilling and loading of holes with dynamite, condensed as follows:

As a general rule the drill holes and charges for dynamite can be and should be comparatively small. In heavy work, however, the holes should be larger in size and less in number, and the amount of dynamite should be proportioned to the work to be done. A general rule applicable to all explosives is: That the quantity of explosive should not only be proportionate to the resistance, but the hole should be proportionate to the explosive, or the explosive to the hole.

Tamping dynamite is of great importance. Mr. Eissler says that it is a fallacy to suppose that dynamite "strikes downward" more than upward, and that tamping is thus useless. By reason of its quickness of action dynamite, without tamping, will do much work where gunpowder would do nothing; but the former will do much more effective work when tamped. In deep and down holes a sufficient amount of water makes a good tamping, but sand, brick dust or clay are much better. A shallow tamping of water has little effect. In a fissured rock the charge should be surrounded with mud, clay, sand or water, when possible. In tamping dynamite use the same precaution for putting in the first portion of the tamping as specified for black powder.

As a precautionary measure, it is well to push a ball of old newspaper just over the primer and under the tamping. If the shot misses fire this paper will indicate the nearness of the explosive, in removing the tamping for putting in another cartridge, as before described. The paper also prevents the scraper from coming in contact with the fulminating cap.

To insure effective work the dynamite must not be frozen; the fuse must be good and properly fitted and kept in the cap; the cap must be kept dry, and must not be withdrawn from the explosive.

Dynamite, as a rule, throws rock less and breaks it more, and extends its effects much deeper than ordinary gunpowder. The great advantages of modern explosives, says Mr. Eissler, consist not so much in diminishing the cost of explosives, as in increasing the amount of work done. The difference in the cost of high explosives and gunpowder is trifling in comparison with the difference in cost of drilling, charging, tamping, convenience in wet work and effectiveness of blasts.

Effect of Nitroglycerine Fumes.—The best account of the effect of nitroglycerine fumes upon workmen exposed to them is probably found in a paper presented to the *Medical Record,* in 1890, by Thomas Darlington, M.D., of New York. Dr. Darlington bases his article upon 1,300 cases of asphyxia, partial asphyxia and poisoning resulting from the product of dynamite combustion, and treated by him during the construction of the new Croton Aqueduct for New York City.

He divides his cases into two classes; acute cases, where the men inhaled considerable quantities of the gas at one time; and chronic cases, where the men constantly breathed a small amount of the gases. In the acute cases, the symptoms are: giddiness, a trembling sensation, frequently nausea, sometimes vomiting, a fullness in the head, and intense headache; the heart's action is increased and the pulse is full and round. If the man is brought into sudden contact with a large percentage of the poisonous fumes—as just after a blast—the giddiness is immediately followed by unconsciousness, and the patient presents the usual appearance of asphyxia. The comatose condition soon passes away and is succeeded by drowsiness, languor, cold perspiration, intermittent pulse, and generally nausea and vomiting. Nearly all the cases mentioned recovered, no matter how serious they seemed at the time.

In the chronic cases the four prominent symptoms are: headache, cough, indigestion, and disturbance of the nervous system. The cough is similar in character to that of *pertussis,* or malaria. In nearly all cases there is a continuing headache and neuralgia. As soon as the patient is removed from the tunnel and put to work above ground, he steadily improves and will

finally recover entirely. Men who previously suffered from dyspepsia or neuralgia are made much worse by dynamite smoke.

In treating these cases, Dr. Darlington proceeded as in cases of asphyxia, adding to this treatment cold applications to the head; and he administered subcutaneously atropine, ergotine, or other vaso-motor stimulants. He recommends that workmen carry small vials of aromatic spirits of ammonia for immediate use, in case of necessity, as he believes that a nitrate is formed in the blood from the decomposition of nitroglycerine. The inhaling of ammonia also has a beneficial effect.

Hints in Power Drilling.—In seamy rock, drills mounted on a bar are apt to bind in a hole, and much time is lost in pounding them loose. Instead of discarding the power for a hand-drill, some miners advise the use of the tripod as a mounting in such cases. The whole machine can then be moved slightly by raising or lowering one of the legs, and the trouble due to binding is entirely done away with.

In overhead stoping, however, a tripod cannot be so readily set up or moved, because of the irregularity of the broken rock on which it stands. But in such case a rough platform of lagging can be used to advantage. Or a small wooden triangle answers even better than the platform, as it holds the tripod and is readily blocked up.

To facilitate drilling in seamy ground it is recommended to make the short bits, used first, larger in diameter than the long ones. And another expedient is to use drills having four shoulders or wings, extending 6 or 8 inches up the drill-shank from the cutting edge, and only a trifle less in diameter than the drill. These wings check the tendency of the cutting edge to follow the slant of a seam.

To Prevent Crushing of Shaft Timbers by Blasting.—Mr. C. K. Colvin, M. E., of Denver, Colo., describes a "float," or a device used to prevent the crushing of the bottom timbering of a shaft by blasts. This consists of two thicknesses of 1-inch boards laid crosswise and faced on each side with $\frac{1}{4}$-inch boiler-iron, well bolted.

The wood center acts as a cushion to protect the plates. This float is built at the bottom of the shaft, and is large enough to extend at least 2 inches beyond the timbers. It is supported at the four corners by 2-ton chain blocks, and just before firing it is pulled up tight against the bottom timbers. There is a "bucket-hole" through the center of the float and this is closed by a chain net. After some months' use the float is usually battered into a cup shape; it is then turned over so that it will be battered back again.

CHAPTER IV

SHAFT-SINKING

Location of shafts—Dimensions—Relation of shaft-work to tunneling proper—General conditions of shaft-sinking—Forces exerted on timbers and precautions to be observed—Steel shaft-house—Cages and skips—Cheap form of hoisting-cage and head-house—Shaft-sinking in wet gravel and quicksand—Sheet-piling shaft.

At the present time shaft-sinking is largely confined to the extraction of minerals of various kinds and to the exploitation of city subways, or subaqueous tunnels. In the days of black powder and hand-drilling, shafts were sunk at frequent intervals on railway tunnels of any considerable length, for the purpose of providing a greater number of working faces and thus hastening the completion of the work. The use of high explosives, power drills and improved machinery for removing the debris have so increased the rate of progress in tunneling work that the old-time necessity for a number of shafts has largely disappeared.

Location of the Shaft.—Where a shaft is necessary it may be located directly upon the center line, or to one side and outside the width of the tunnel. In the United States the former position is very generally preferred. The shaft on the center line is better adapted to transferring the alignment to the tunnel below; it is more convenient for the laying of track and the handling of cars at the foot of the shaft; and the center shaft costs less than one for which a cross-cut has to be made. In treacherous soil the side shaft may also bring about a disturbance of the material at the side of the tunnel and lead to a dangerous slip.

Dimensions.—The horizontal dimensions of a shaft must be carefully proportioned to the character and amount of material to be hoisted, and to the pumping and ventilating plant that

may possibly be needed. A shaft that is too small for the work proposed is an endless source of trouble and expense, for the shaft is the neck of the bottle through which everything must pass in and out, and its dimensions are thus the controlling factor.

The usual shaft is rectangular in plan and nearly twice as long as it is wide. This form permits of the establishment of separate compartments for hoisting and for the pumping and ventilating pipes, and provides means for the constant inspection and repair of the pipe system without interfering with the regular hoisting work. Unless the shaft is a permanent one ladders or a stairway are seldom provided. Square or circular shafts are badly adapted to the disposition of the plant.

Shaft Sinking.—Owing to its vertical or sharply inclined position and the consequent collection of water on the bottom, or working face; to its limited dimensions; to the extraction of the material by a bucket-hoist, and to the necessary shifting of pumps and pipes, competent authorities estimate that it requires from 15 to 20% more time to sink a shaft per lineal foot of advance than to drive a tunnel heading of similar dimensions. The cost is also much greater owing to the conditions cited.

The method adopted for sinking any shaft depends entirely upon the character of the material to be penetrated. If this material is fairly solid and homogeneous rock, with little water, the task is a comparatively simple one. But if the material is water-bearing, is soft or liable to run into the bottom of the shaft as it is being excavated, it is only a question of time when the ground about the shaft will be "moving" and exerting unequal and destructive pressures upon the shaft timbering, tending to tear these timbers apart vertically. Every precaution must be taken to prevent this movement in the adjacent soil by careful timbering, and by floors, if the soil is very soft. In very bad soil iron cylinders are sometimes employed, either sunk in solid rings added from above and forced down, or by segmental rings bolted into place at the bottom.

In loose or running ground, with any system of timbering

that may be adopted, the important precautions to be observed by the timber-men are the following: Make the timbers heavy enough to resist all lateral pressures. To guard against the horizontal separation of the sets, or timbers, see that these sets are securely tied together vertically, thus anchoring them to timbers on firm ground above—if such ground exists; and in any event, hang the timber together as the shaft is built downward. Above all, prevent, if possible, the removal of any ground outside the cube of the shaft itself; any space thus left outside the timbers by careless excavation will be filled up by pressure from above and gradually start a dangerous movement in the soil about the shaft. In very soft ground the material in the bottom may have a tendency to swell, or "rise" in the shaft. This is an exceedingly troublesome problem to deal with, and is overcome usually by flooring the bottom of the shaft and strongly bracing from above, and sinking this floor in sections made as small as possible. As a rule, in bad ground, all openings made in the sides for new timbers, or in the bottom for sinking, should be so small as to be always under control, carefully "poling" the space to be finally provided for a new timber, in such manner as to prevent a "run" of soil from without.

In sinking a shaft or in driving a tunnel too much stress cannot be laid upon the importance of adhering as closely as possible to the true section of the excavation. As remarked before, voids outside this section inevitably invite and bring about pressure, and the final amount of this stress cannot be even estimated. If such voids are unavoidable, as is often the case in tunnel driving, they should be carefully and completely filled by masonry or by packing of loose stone. And it is the duty of the engineer to see that this is done. With the purpose of hastening the completion of a certain piece of masonry careless workmen are too prone to scamp this packing, with the impression that it will never be discovered. This is especially the case in tunnel lining; and the writer has personally known cases where a man could stand upright in the space left over a tunnel arch, and where empty cement barrels were substituted for the stone packing called for in the specifications. As a matter of fact,

few tunnel linings fail under direct pressure upon this lining; in nearly all cases failure can be directly traced to unfilled voids.

Various methods are employed for sinking a shaft through sand or other water-bearing material of a comparatively homogeneous nature; and some of these methods are described in more detail in succeeding pages. Among these methods may be noted the plenum pneumatic, or compressed-air process, operated either in iron cylinders bolted together by horizontal flanges, or in caissons connected with the part above the water level by cylindrical shafts. The use of compressed air in this connection is practically limited to a depth of about 110 feet, by its effect upon the human organism, and it is generally employed in foundation work for piers in bridges or building construction.

The freezing process is employed under circumstances which warrant the necessary expenditure, in sinking a shaft through water-bearing material. In this process the ground and the contained water is frozen to a solid mass for some distance outside the limits of the shaft, by first sinking vertically a circle of special double pipes, penetrating to the full depth of the proposed shaft, and then circulating through these pipes brine or other freezing compounds. When the ground is sufficiently solid the shaft is excavated and lined in the usual manner. This process is described in more detail in a following portion of this book.

The Kind-Chaudron method of shaft-sinking had its origin in Belgium and has had a limited use in sinking shafts in the coal regions of that country. Briefly stated, the process consists in sinking iron cylinders by using heavy and specially devised cutters for breaking up the bottom material; these being operated from the top of the shaft and through any depth of water in the shaft. The material thus broken up is removed by dredging through the water, and as the cylinder sinks, its length is increased by adding sections at the top. It is an expensive method, slow in operation, and is liable to fail from the difficulty of keeping the cylinder in a vertical line, and its consequent jamming.

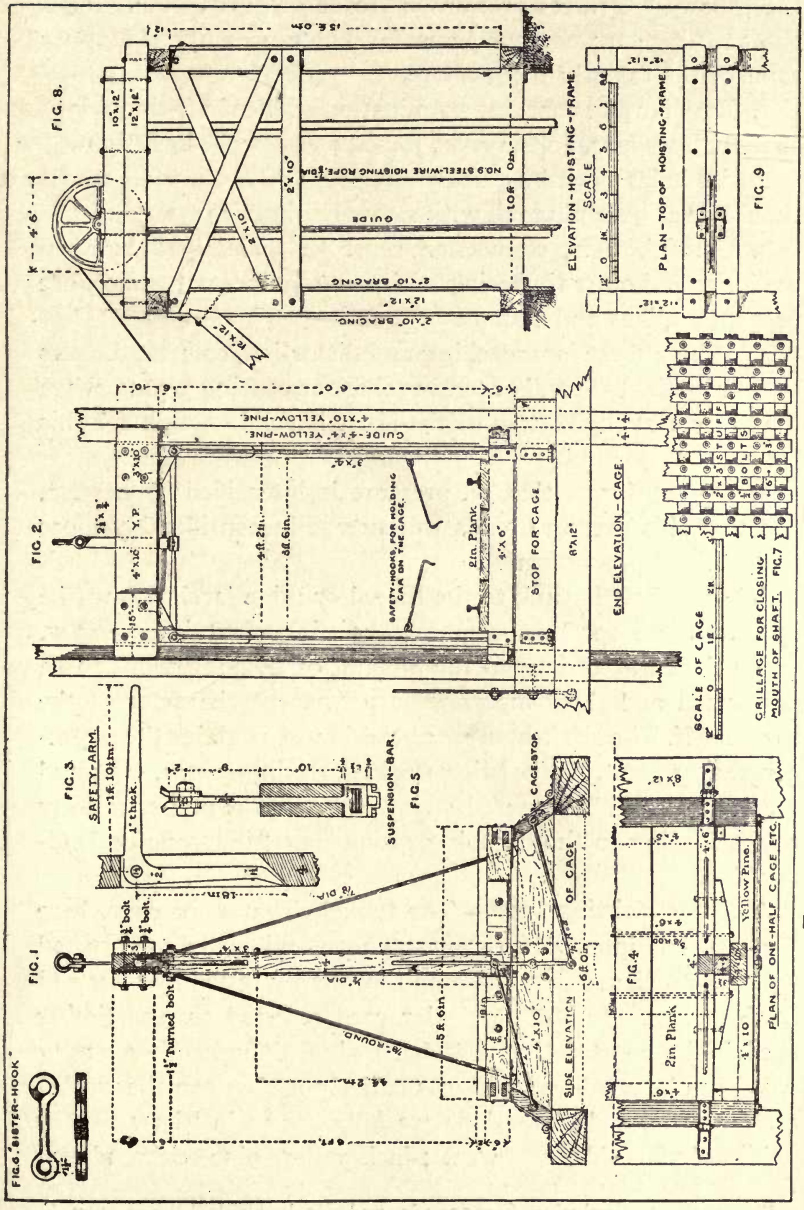


FIG. 10.—A Simple Form of Hoisting-cage and Head-house.

In his monumental work on tunneling* Mr. Drinker gives the following general precautions to be observed in sinking a shaft through treacherous ground. These precautions amplify some of the remarks made above.

1. Regular and constant examination of the shaft-timbering; so that all wedges, bolts, props, joints, etc., may be kept tight.

2. All holes must be quickly stopped, and even small cracks should be at once plugged with straw or similar material.

3. Careful, tight connection must be maintained between the inner and outer timbering. If wedging does not suffice, use props, or spikes and clamps.

4. Where there is wrenching and distortion, connect the sets by longitudinal "bars," or put in rakers or bearing beams, when the ground at the bottom of the shaft is solid enough for this purpose.

5. Do not forget that all pressure is intensified by neglect, and that this pressure tends to increase in considerably more than a direct proportion.

After a shaft is sunk to the tunnel or mine level, it must be operated; and for this purpose a hoisting plant is necessary, proportioned according to the amount of hoisting work to be performed and the temporary or permanent character of the work itself. The shaft-house, or head-house, contains the steam-generating plant, the hoisting engines, drying-rooms, etc.; and the head of the shaft must be equipped with the proper railway tracks leading to the dumping ground, or to storage or loading bins.

A Simple Hoisting Cage.—The tunnel elevator, or cage, here illustrated is intended to show a cheap and easily constructed hoisting appliance that has been thoroughly tested by long and hard service. In the particular case referred to, the timber used in its construction was hard pine, though other strong wood can be employed. It was entirely made upon the works, and its detail and dimensions are fully shown in Fig. 10.

The shaft-guides were 4 x 4-inch yellow pine sticks, planed

*"Tunneling, Explosive Compounds and Rock Drills," by Henry S. Drinker, E.M.; New York, 1878, John Wiley & Sons.

on three sides and secured by $\frac{5}{8}$-inch counter-sunk bolts to a 4 x 10-inch timber as shown. These guides were kept well oiled. The safety appliance was made of a pair of steel-pointed chisel-arms, secured at the elbow by a $1\frac{1}{2}$-inch pin passing through the uprights of the cage; and these pins practically carried the whole weight of the cage and its load. On the bottom of the cross-head of the cage frame an iron plate, $\frac{1}{4}$-inch thick, was secured; and against this plate reacted a strong, three-leaf spring, passing through the bottom of the bar carrying the hoisting rope. The inside ends of the chisel-bars worked in a box secured to the bottom of this suspension-bar. The spring was adjusted so as to resist the weight of the empty cage; and so long as the hoisting rope was intact the vertical part of the chisel-arm lay inside the socket provided in the uprights. But, should the rope break from any cause, the spring was released, and the horizontal arm was pushed downward by it; the vertical or chisel-arm was thus pushed outward and into a position to cut into the 4 x 4-inch guide member as the cage descended. In this particular cage the safety device was severely tested several times by the breaking of the hoisting rope, with a full load on the cage. In each case the cage was brought to a standstill with a maximum fall of 20 inches; the guides were badly cut up in the operation, but their construction permitted the rapid replacement of the damaged portion.

The "cage-stop," for holding in adjustment the platform track and the track leading to the dump, was effective and easily handled. The cage in ascending opened the stops; and these fell into place by gravity as the cage passed through them. In sending the cage down, the latter was hoisted a little, and the stops were thrown back and out of its way by the hand-lever shown.

As an open shaft-mouth is a source of frequent danger to the top-men, this shaft was always closed at the top, either by the cage itself or by a grillage made as shown. This grillage was long enough to extend over the sides of the opening and strong enough to support a car. When the cage came up it lifted the grillage with it on the cross-head of the

cage. The hoisting frame is sufficiently well shown in the illustration.

Steel Shaft-house.—During 1902 the Oliver Iron Mining Company, of Duluth, Minn., put down two shafts at Ely, Minn., 1,500 feet apart, but both operated by a single hoisting plant. As the house at each shaft is constructed of steel, a brief description of the plant is here given, as showing the latest practice in this direction.*

The shaft-house here shown (Figs. 11 and 11a) was built by the American Bridge Company at its Minneapolis shops, and is 30 feet wide on the face, 75 feet deep on the ground level,

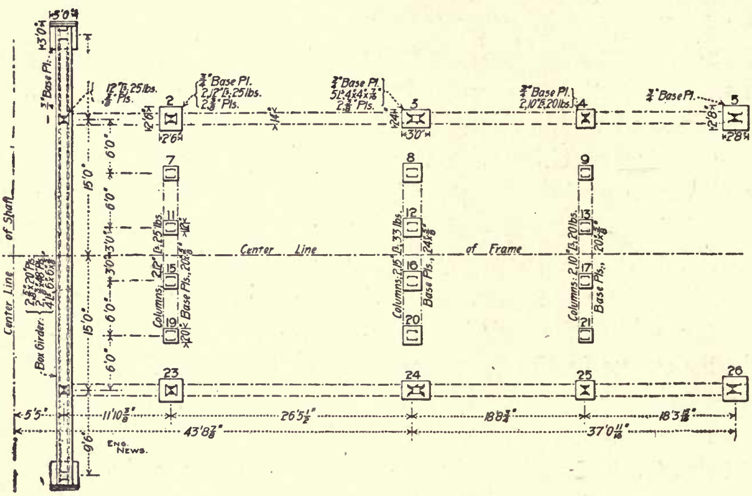


FIG. 11a.— Foundation Plan of Steel Shaft-house, Ely, Minn.

and is 158 feet high from the collar of the shaft. About 265 tons of structural steel were used in its erection.

The main frame is made of columns composed of pairs of steel channels, with horizontal lines of steel channel-framing between them. As it is not advisable to build column foundations close to the shaft, the first columns are supported on a heavy box girder. The two heavy, inclined columns at the rear of the

*For a detailed description of this plant, by Mr. Frank Drake, M. Am. Inst. M. E., Chief Engineer of the company, see *Engineering News,* Nov. 19, 1903.

house act as braces to resist the pull of the hoisting ropes, which pass over the 12-inch grooved sheaves near the top of the house. At a height of 33 feet above the shaft is a projec-

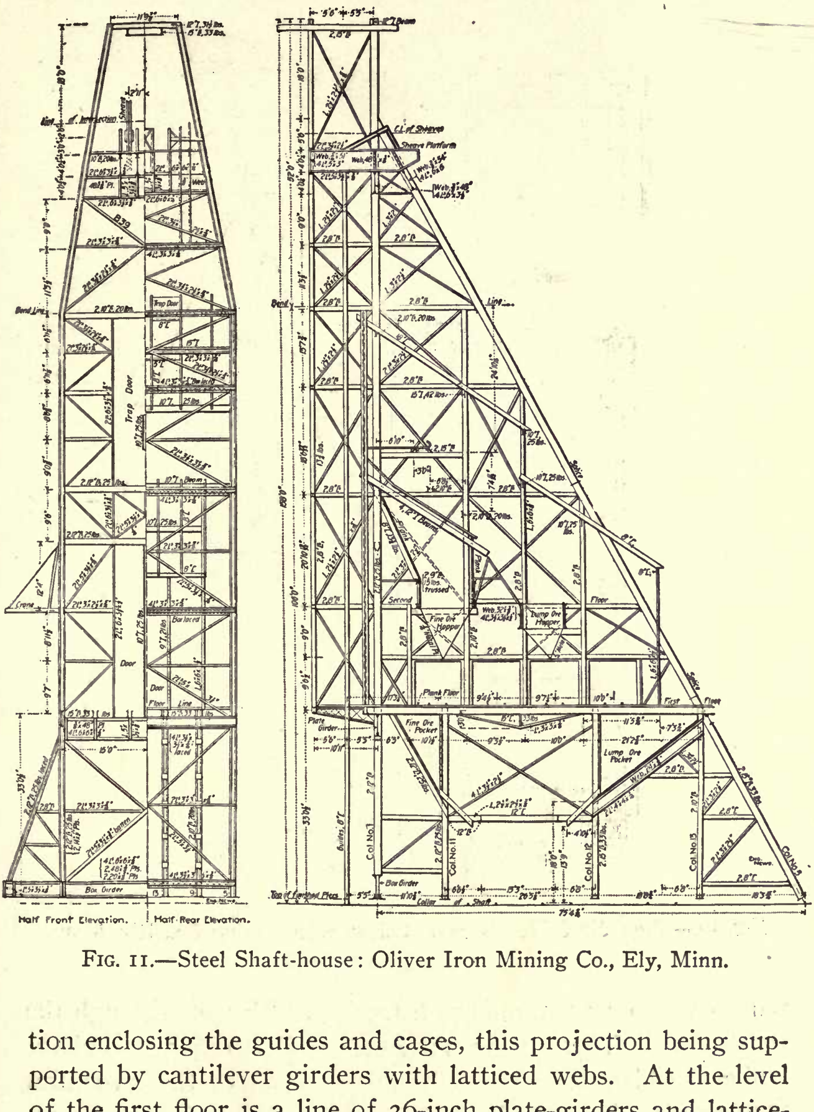


FIG. 11.—Steel Shaft-house: Oliver Iron Mining Co., Ely, Minn.

tion enclosing the guides and cages, this projection being supported by cantilever girders with latticed webs. At the level of the first floor is a line of 36-inch plate-girders and lattice-

girders between the outer columns, instead of the 15-inch channels between the inner columns, as shown in the section.

The fine and lump ores are dumped from the cages through separate hoppers into bins; from the latter it is discharged as

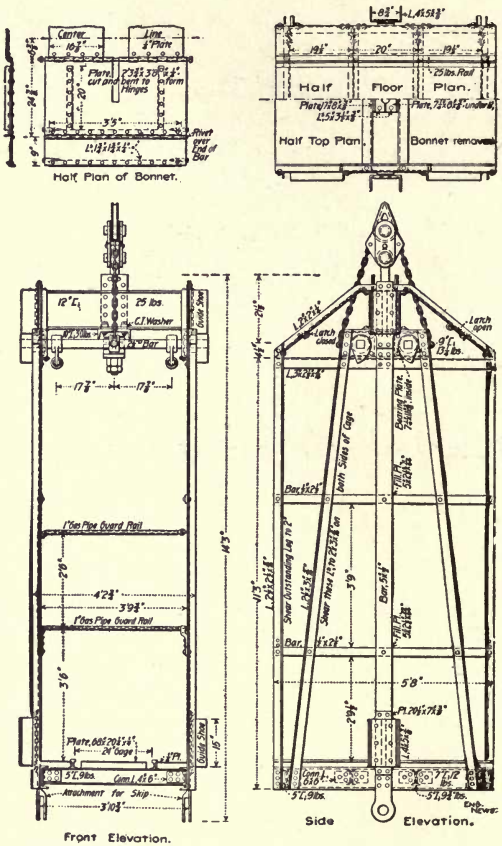


FIG. 12.—Cage for Sibley Shaft: Oliver Iron Mining Co., Ely, Minn.

required into cars standing on tracks which pass through the shaft-house. These hoppers are made of 5-16 inch steel plate; while the bins have plank lining attached to the structural framework. The whole shaft-house is sheathed with corru-

gated steel, painted with two coats of iron-ore paint on all its members, excepting only the interior of the hoppers and the lining woodwork.

Cages and Skips.—As one shaft is vertical and the other inclined, the cages and skips used differ in design; and both types are here shown in all their dimensions. All of the structural material is soft, open-hearth steel; the floor is 2-inch plank covered with $\frac{1}{4}$-inch steel plate. The two draw-bar springs are

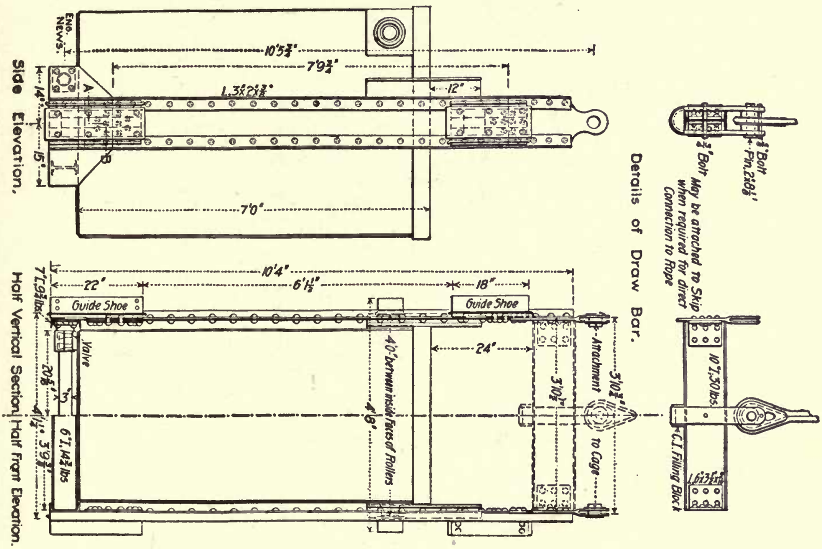


FIG. 12a.—Skip Used in the Sibley Shaft.

made of square steel, and they have an outside diameter of $6\frac{1}{2}$ inches, and a length of 7 inches when free. Under 10,000 pounds load the compression is $1\frac{1}{2}$ inches.

The skip for the vertical shaft weighs 4,678 pounds, or 4,935 pounds with a lip. The construction is plainly shown in the illustrations.

Shaft-sinking in Wet Gravel and Quicksand.—The Penn Mining Company, of Norway, Mich., in 1890 found it necessary to sink a shaft through 60 feet of glacial drift very heavily

charged with water. It was decided to sink a caisson, or drop-shaft, to reach the underlying impermeable stratum.

The top of the shaft (Fig. 14) was 6 x 13 feet inside; the bottom was made 4 feet larger each way, or 10 x 17 feet inside; and to within 12 feet of the bottom the shaft was divided into three compartments, the middle one being uniformly 4 feet

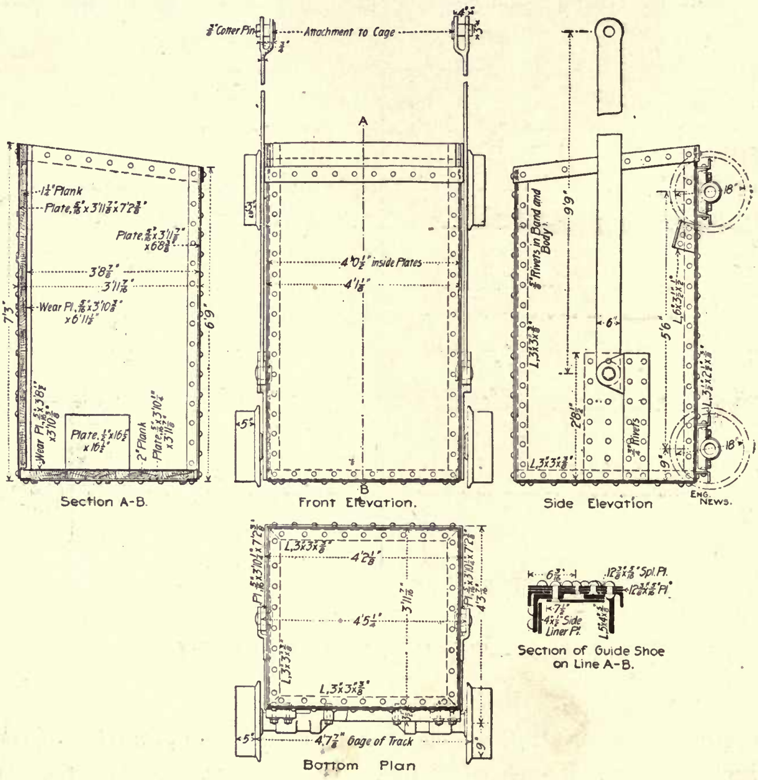


Fig. 13.—Skip for Savoy Shaft.

wide. As shown in Fig. 15, the pumps were placed in the two end compartments, and these were covered over to admit of sand for loading the caisson. The middle compartment was used for hoisting, the pipes, etc. A ventilating box was put in one corner of the shaft.

The bottom timbers of the shaft were oak, 15 inches square, beveled to 6 inches. Above these came white pine sticks 12 inches square, framed in sets and bolted together and to the shoe with eight bolts each 5 feet long. The successive sets were reduced 1 inch in width and length, until at 48 feet above the bottom the dimensions corresponded with the top set. The corner-posts were 12 inches square, and broke joints with each other. They were bolted to every other side and end piece. The bolts were put in from the inside, with the nuts countersunk; they were thus easily recovered when the corner-posts were removed. The side-posts were secured in a similar manner, one at each corner of the middle compartment. At every 5 feet 12-inch dividers were used.

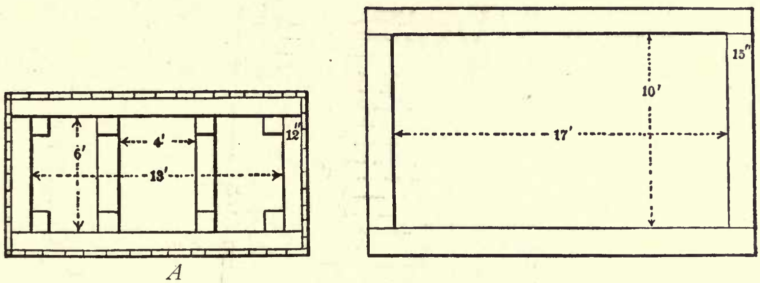


FIG. 14.—Top and Bottom Sets: Harrison Shaft, Norway, Mich.

After the ground had been leveled the caisson was built up and bolted to a height of about 30 feet. The seams were carefully caulked outside, and 3-inch plank was spiked on vertically to protect the caulking and still further strengthen the caisson. Steam hose, and later elbowed pipe, were used to connect the pump with the boilers.

The quantity of water to be pumped was estimated at 1,500 gallons a minute; and this water was charged with fine, sharp sand, that rapidly wore out the pump-linings, causing delay. The shaft was sunk the 60 feet in sixty-three days, including all delays.

The flow of water at the bottom was stopped as follows: The corner-posts were taken out, the bolt-holes were plugged,

and the inside of the shaft was caulked. Then the shaft was sunk 11 feet into the ledge. To seal the bottom of the drop-shaft, a set of 12 x 12-inch timbers, 6 x 13 feet inside, was carefully placed in line with the top set, as shown in Fig. 16, and extending about 6½ feet below the shoe. This set was

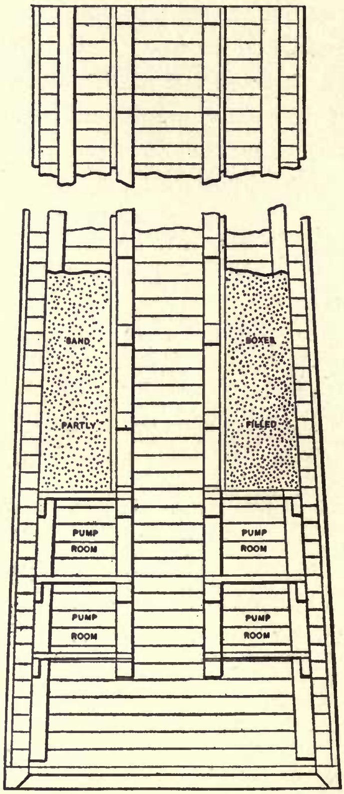


FIG. 15.—Harrison Shaft: Longitudinal Section.

thoroughly blocked against the rock by wedges, and six other sets were built upon it, each being bolted to the one below. A thin layer of clay was put over the wedges, and, as the successive sets were put in, a concrete of equal parts of sand and cement was packed between the timbers and the rock. Through the top set, which was about on the level of the shoe,

twenty 2-inch holes had been bored; and behind these holes was laid a 4-inch layer of broken stone. Three other sets were laid on this last set, gradually widening out, with the top set bolted to the sides of the caisson. The space behind these was also filled with concrete, and this was allowed to set. The holes

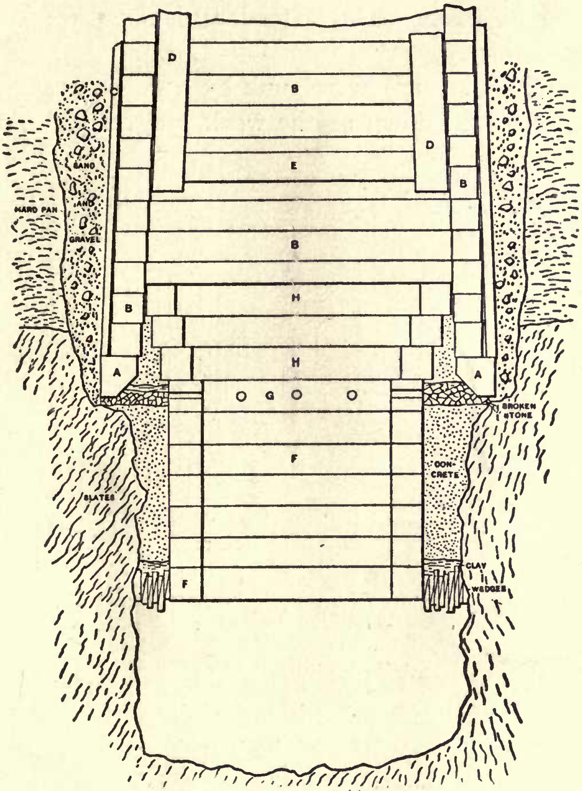


FIG. 16.—Method of Closing the Bottom of the Harrison Shaft, Norway, Michigan.

in the special set were finally plugged, and the inflow of water at once dropped to 200 gallons per minute. Thorough inside caulking further reduced this flow to 90 gallons.

Sheet-piling Shaft.*—The Brooklyn shafts for the extension

*For a detailed description of this work see *Engineering Record,* Oct. 31, 1903.

of the New York Rapid Transit Railway under the East River are made of sheet-piling, as here shown. The two shafts are 50 feet apart on centers, and each one is 23 feet 11 inches by 20 feet 2 inches in inside dimensions, and is 65 feet deep. The material penetrated is as follows: Ten feet of loam, 35 feet of boulders and gravel, and the remainder is in sharp, fine sand that runs quite freely. The water level is about 60 feet below the street surface.

The shafts (Fig. 17) were sunk by open excavation inside sheet piling driven down as the work progressed. An outer

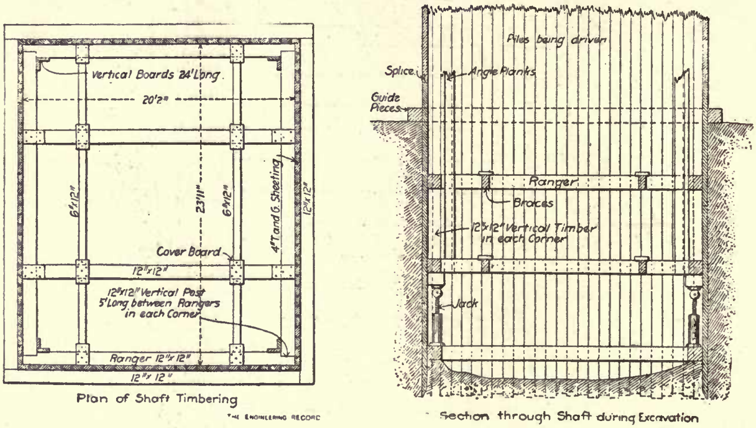


FIG. 17.—Sheet-piling shaft: New York Rapid Transit Railway, Brooklyn Extension.

guide frame of 12 x 12-inch timbers was first laid down on the ground; and inside of this were placed the 12 x 12-inch rangers, braced as shown. In the 4-inch space between these sets the 4 x 10-inch tongued and grooved braced sheet-piling was driven. These piles were cut at the lower end to an angle of 60°, and shod with a thin, bent steel plate 7 inches wide.

The sheet-piling was driven by a steam hammer, commencing at one corner of the shaft and driving successively around the four sides, driving each pile uniformly one to two feet at a time. A gang of ten men, working ten hours per day, excavated 15 feet of shaft in one week.

The sheet-piling was 65 feet long; and each pile was made

in five sections with a halved butt and lap-joint, each joint secured by eight or more 5-inch wire nails. The excavation was kept just above the bottom of the sheeting. The corner sheeting was dovetailed and bolted together, and driven as one pile. The bottom ranger set was braced up horizontally from

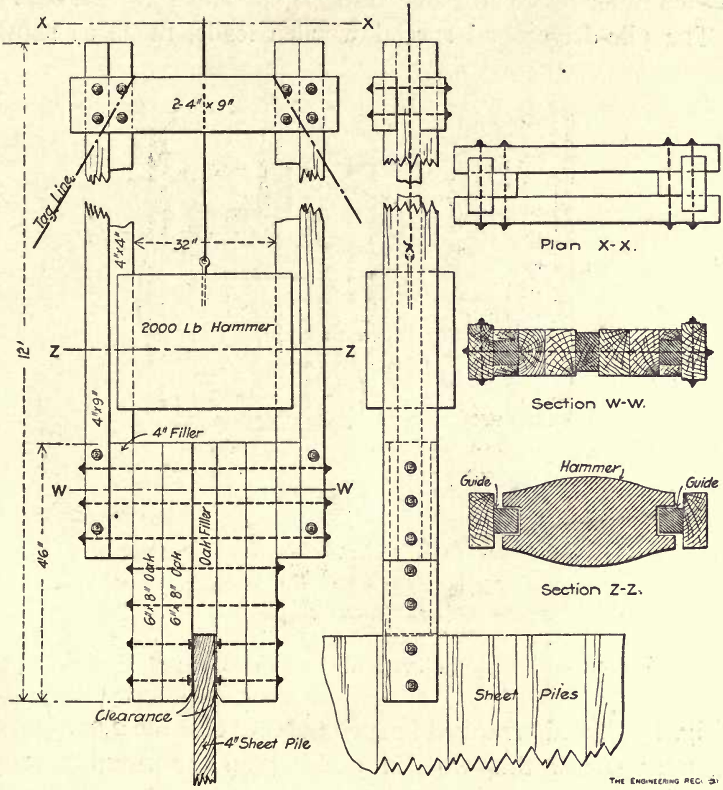


FIG. 17a.—Device for Cushioning the Blow of the Hammer on Sheet-piling.

the bottom of the pit, while the piles were driven against it. After the excavation had been carried about 2 feet below this set a second ranger set was put together at the bottom of the pit, and 10-ton hydraulic jacks were set up at each corner of the shaft reacting upon the frame above. As the digging proceeded these jacks drove the bottom set downward, and this

was continued until there was a space of 6 feet between the sets. The upper frame was now temporarily supported on cleats nailed to sheeting, and the jacks were removed. Digging was resumed, and as soon as 2 feet had been gained the above operation was repeated. The ranger sets were hung to each other by a pair of vertical planks nailed in each corner.

The pile-driver had special wooden leads, made as shown

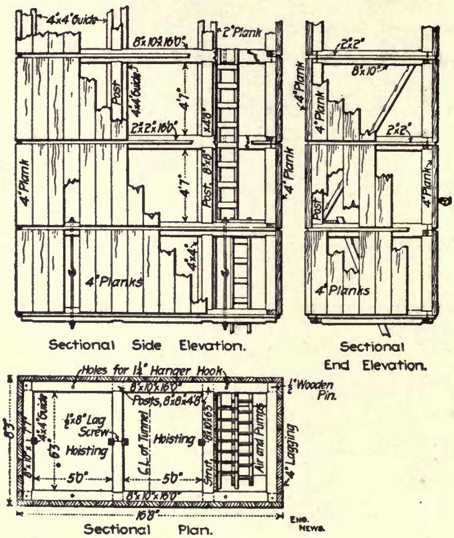


FIG. 18.—Plan and Elevation of Shaft at Aspen Tunnel.

(Fig. 17a), and arranged in such manner that the 2,000-pound hammer struck this wooden packing and thoroughly drove the piles.

The accompanying illustration (Fig. 18) shows the method adopted for timbering a shaft on the Aspen tunnel of the Union Pacific Railway. This shaft was 331 feet deep, and penetrated hard but seamy sandstone, carrying very much water below the 257-foot level.

CHAPTER V

PRINCIPLES OF TUNNEL TIMBERING AND DRIVING

General rules—Choice of timber—English method of timbering as applied in the United States—Belgian and Belgian-German system—German system—Austrian system—American system—Driving through loose gravel—Crutch system—Timbering a sand tunnel—Meem poling-board system—Iron crown-bar system—Old rail crown-bars, their advantages and disadvantages—Steel-lined tunnel—Sand-chamber and caisson method—Pilot-tunnel system—Sewer tunnel in quicksand—Dry-sand tunneling—Enlarging tunnel in soft ground—Sewer tunnel in dry sand.

The particular manner of timbering a tunnel will depend upon the nature of the material and the experience and choice of the miner conducting the work. But some of the fundamental principles underlying work of this character may be noted as follows:

Compression is very largely the force against which the miner has to contend. Therefore, all joints should be of the simplest character, as all notching, mortising, dovetailing, etc., tends to weaken and split timbers under pressure; and where angles are necessary flat surfaces and wide angles only can be used with any safety for abutting timbers. The pressure itself tends to tighten the joints; and, to avoid slipping, heavy spikes driven outside of the upright timbers are most satisfactory.

In nearly every system of timbering, wedges are an important factor in securing tightness between surfaces. Wedges are employed to tighten joints and to lengthen timbers that are too short; and as they may be cut out, they permit the removal of timbers in heavy ground and under pressure.

As a rule, spikes and nails should not be driven into the timbering proper, the one exception being the heavy spikes, or "brobs," referred to above, to keep the foot of a post from slipping, or the top of a post from coming out from under a

cap. But in both of these cases the spikes are driven outside of the post or strut, and not into it. A great part of the timbering used in a tunnel must come down again, and it may be essential to remove it as quickly as possible. Hence, any spiking of timbers delays and makes more difficult the work of removal or shifting. Screw-bolts are made to fasten together

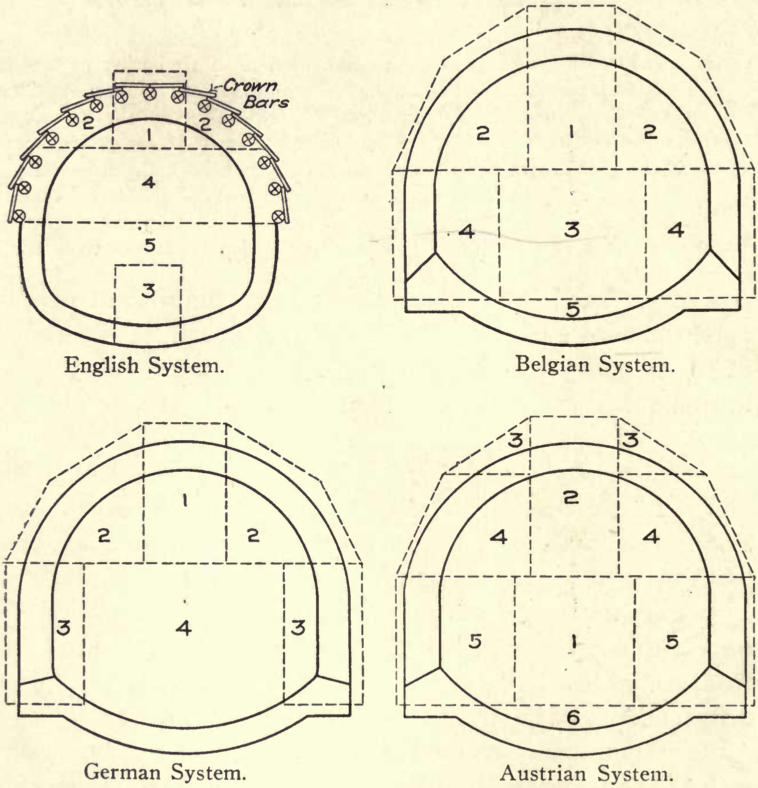


FIG. 18a.—Diagrams Illustrating Four Systems of Tunnel Attack; the Numerals Showing the General Sequence of Excavation.

the segments of arch-centering, in making fish-joints, etc., but these are easily removed. Where the risk will warrant the cost, rings or bands may be employed to prevent timbers from splitting; and in shaft-sinking, iron hangers, heavy steel cables or tie-rods may be necessary to hold the sets together vertically.

Another very useful appliance in tunnel-timbering is a screw-jack fastened to one end of a heavy timber. These jack-timbers save time, and are economical of timber in special cases; and as they are quickly adjusted to length and applied, they may be very useful in an emergency.

Tunnel-timbering is a temporary means of supporting the roof or sides until the tunnel section can be excavated and the permanent masonry lining can be put in place. As timber is perishable in any but very wet tunnels, it should be removed wherever this is possible; and it is economy to use the timbers over again where this can be safely done. The best system of timbering, therefore, is one that permits proper drainage and the maximum of room to handle the material; that is, sufficiently strong for the forces to be contended with, and that permits ready handling of the separate members and the re-use of the bulk of the timbers.

For timbering purposes a soft, elastic evergreen wood is generally preferable to oak or other hard woods. Pine wood is straight of grain, lighter and easier to handle; it is soft enough to cushion a sudden thrust in bad ground; and as it will bend before breaking, it gives warning of coming danger.

The methods of tunnel attack, timbering, sequence of lining, etc., as generally illustrated in Fig. 18a, vary widely in different countries; and, mainly for purposes of general reference, the essential features of the principal methods are briefly described.

English Method as Applied in the United States.—The main features of this system of tunneling are the driving of a top-heading; the widening out laterally from this heading and the excavation of the full section of the arch; the removal of the bench immediately; and, particularly, the use of heavy crown-bars of timber to hold up the roof timbers, and the withdrawal of these crown-bars as the work progresses, whenever this can be safely done.

The advantages of this system are summarized by its advocates as follows: The large, free space provided facilitates drainage, ventilation, and the easy and economical removal of the debris, this debris being either taken directly from the

bench, or run into cars in a bottom heading. Where the crown-bars can be withdrawn and re-used there is a saving of time, material and labor in bringing down new sets. As the crown-bars are drawn after the arch is in place, this system does not interfere with the masons as much as a system requiring the timbers to be removed as the arch is built.

The objection is made that this system requires the miners

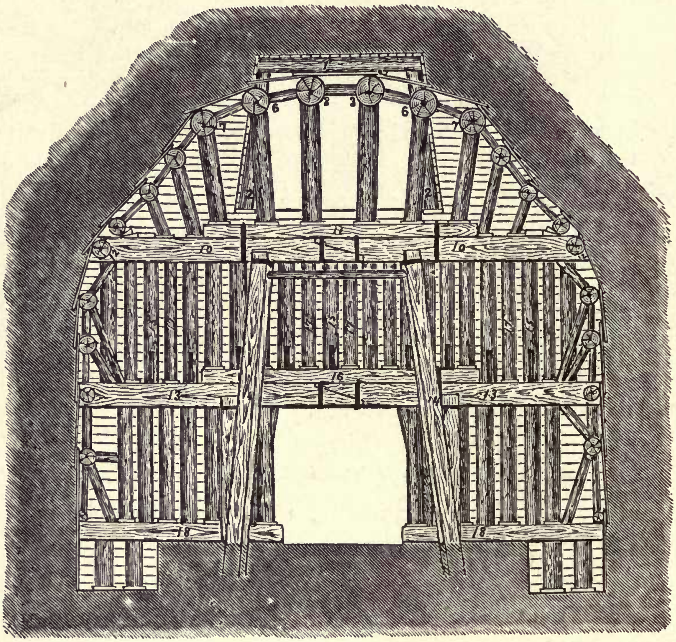


FIG. 19.—English-American Tunnel System; as Applied at the Musconetcong Tunnel.

to be idle while the masons are at work; but the work can be so arranged that other work can be found for the miners.

The English system has been successfully used, with various modifications, for over fifty years in England, in America, and on the Continent; and even in earth and comparatively soft ground it can be safely and economically applied. The two cases (Figs. 19 and 19a) used for illustration are taken from the Musconetcong and the Hoosac tunnels.

Belgian and Belgian-German System.—The Belgian engineers were the first to build the arch first, underpin this arch and build the side walls last, this process being illustrated in Figs. 20 and 21. It commences with a top-heading, which is enlarged laterally until it includes the whole arch area. The underpinning of the completed arch, preparatory to building

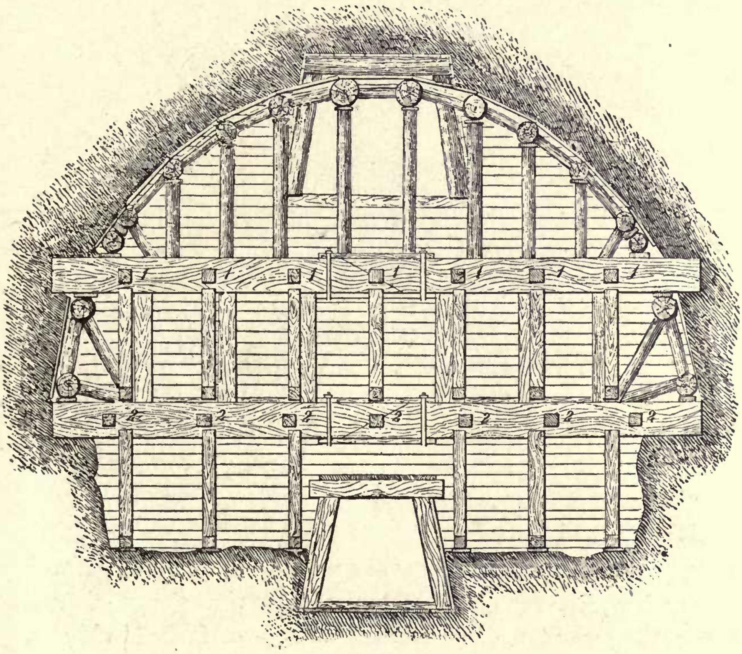


FIG. 19a.—English-American Tunnel System; as Applied at the Hoosac Tunnel.

one of the side walls, is shown in the illustration. Both illustrations are taken from Mr. Drinker's description of the St. Cloud tunnel.

In the German modification of the Belgian system the central core is left to support the roof timbering; but the side drifts are excavated, and in these the side walls are built, the arch being constructed last. French engineers have also adopted the central core system for some of their tunnels, but they build the arch first, as in the original Belgian system.

The claimed advantage of the Belgian system is that it provides a speedy and secure roof under which to carry on the rest of the work of excavation and masonry. But this contention is only true when the roof is a loose rock, demanding some, but comparatively little, support.

The disadvantages are many. In the first place the main

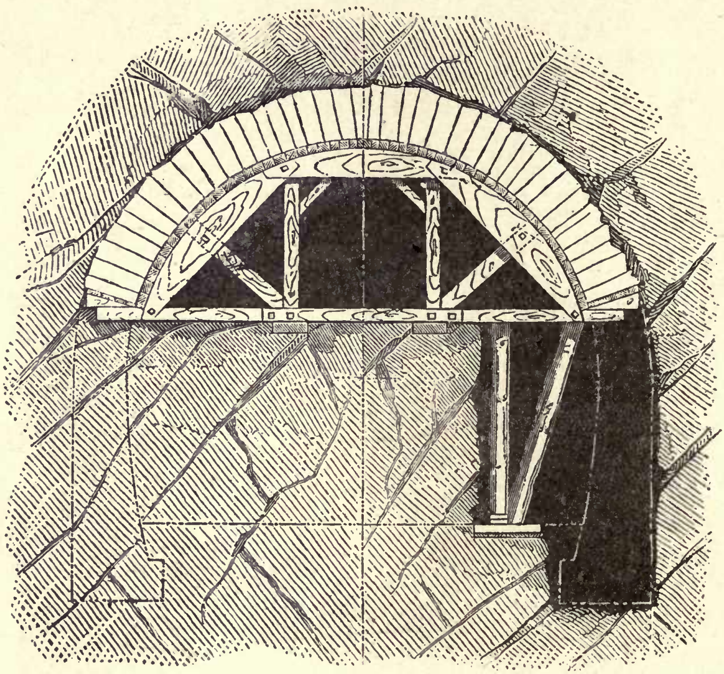


FIG. 20.—The Belgian Tunnel System: St. Cloud Tunnel.

cross-sectional area of the tunnel is not at once accessible; and the successive removal of comparatively small sections at a time is very uneconomical. The underpinning of the arch is also very objectionable to English and American engineers; though Continental engineers have done some good work in this direction, notably in the St. Gothard tunnel. In this Belgian system the handling of the material and removal of the debris are difficult and costly in the small openings provided; and this is especially true in building the arch and the side

walls. The tunnel is also drained at a disadvantage, as a bottom heading driven for this purpose tends to loosen the sides and weaken the temporary supports of the completed arch. And under a common arrangement of the timbering supporting the arch there is a decided tendency to concentrate the load on a single part of the central core. This is contrary to all good tunnel practice.

German System.—While modified in a number of ways, and as conditions may dictate, the essential feature of this system, as

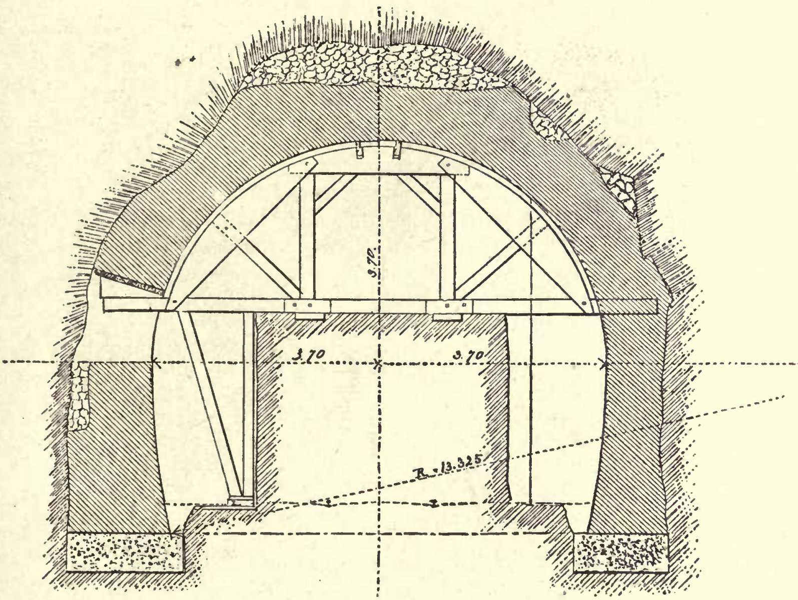


FIG. 21.—Belgian System; Showing Centers and Method of Underpinning the Arch.

shown in Figs. 22 and 22a, is a central core used for supporting the roof. A top-heading is usually driven first, and this is gradually widened laterally until it includes the entire arch section. The excavation for the side walls is then made from the top down, and the building of the side walls precedes arch construction. In some cases, however, the side walls are started in two bottom drifts, which meet the top-heading enlargement.

The German engineers claim that this central core provides

cheap working in hard ground; and as the system is based upon relatively small openings, in soft ground the pressures can be better met. The use of the core is also supposed to save much timbering.

But even in Germany the system is now practically abandoned because of its defects. Owing to these small openings the work is inconvenient and costly; the ventilation is bad; bad bonding is apt to result from the cramped space in which

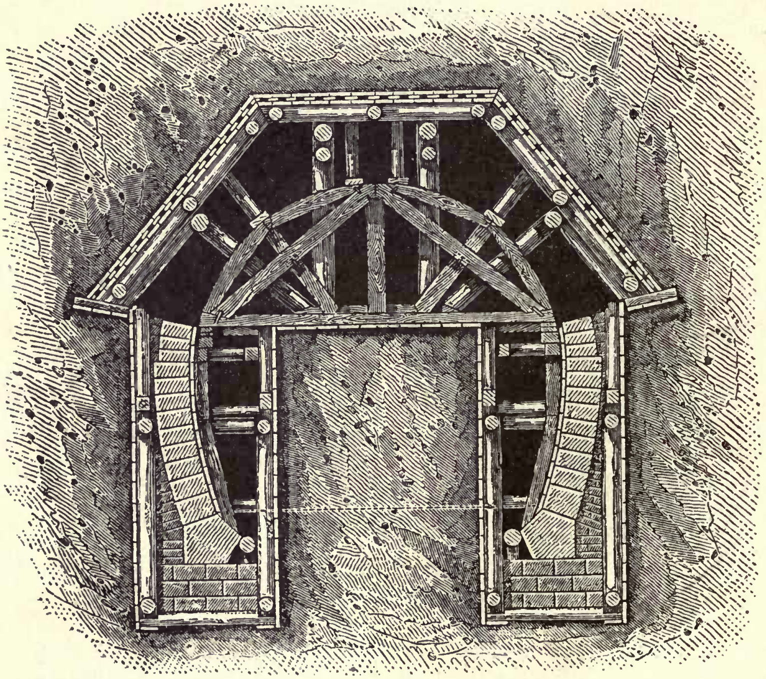


FIG. 22.—German System: Triebitz Tunnel.

the masonry of the side walls has to be laid; it is very difficult to preserve the alignment in a tunnel so constructed, and the arrangement of the timbering tends to a dangerous concentration of load and pressure.

Austrian System.—In its final development this system is characterized by a very strong timber support during exploitation.

It commences with a central bottom-heading; immediately above this is driven a second heading extending to the top of the arch masonry; this last heading is enlarged laterally until it takes in the whole arch area; and finally the bottom-heading is enlarged laterally until it includes the side-wall area. The side walls are built first, and the arch is then made.

The completed timbering arrangement is here shown from

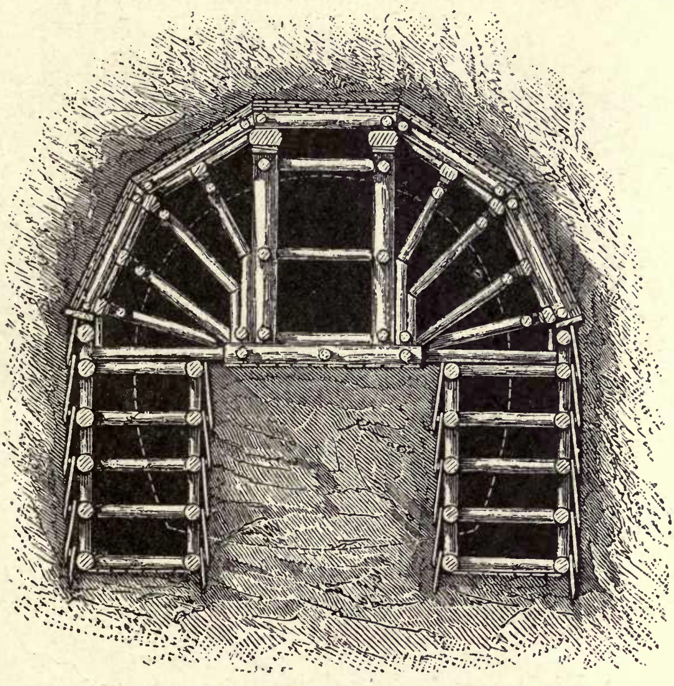


FIG. 22a.—German System: Ozernitz Tunnel.

illustrations taken from Drinker's "Tunneling." The Austrian engineer, Rziha, advocates this system for all kinds of ground, from loose rock to quicksands.

In this Austrian system the central bottom-heading is a good feature, as it well provides for ventilation and drainage. The general arrangement of the supporting timbers, though sometimes crowded, is effective as a rule. All cross and longitudinal

connections are well designed; there is no undue concentration of load at any one point, and the space left for the removal of the debris and the work of the masons is ample, as compared with the preceding systems.

The one marked disadvantage of the system is the overcrowding of the timbers, requiring a large amount of material and handling, and to that extent decreasing the room available for work.

American System.—The so-called American system, as shown

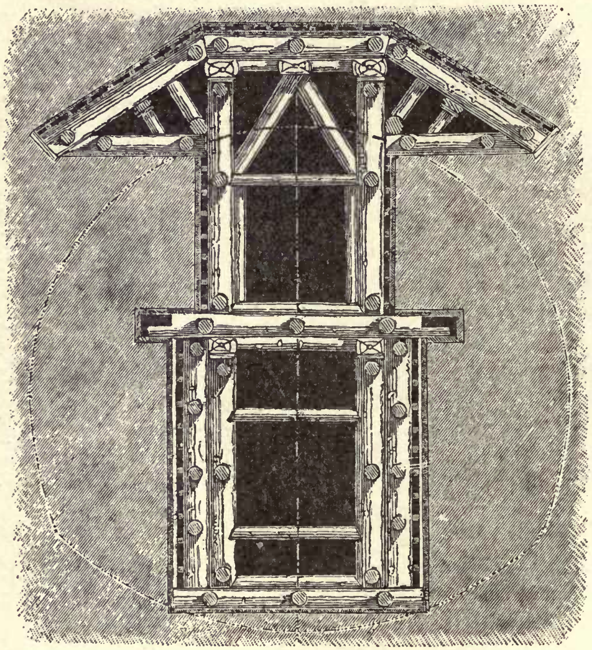


FIG. 23.—Austrian System; Advance Heading and Top Enlargement.

in Fig. 24, is a development, and it had its origin in the conditions imposed by the character of the rock through which a number of the earlier American tunnels were driven. These tunnels were largely located in the coal regions, in slates, shales, and other weak rock requiring ample support. The system it-

self more nearly resembles the Austrian method than it does others described; but it is much more economical of timber.

In this manner of driving a tunnel a central top-heading is usually first driven, and this is enlarged sideways so as to include the full arch area. The bottom is taken out in two benches as the work progresses.

But the essential feature of the system is the construction of the roof support. This is made of nine or more arch blocks,

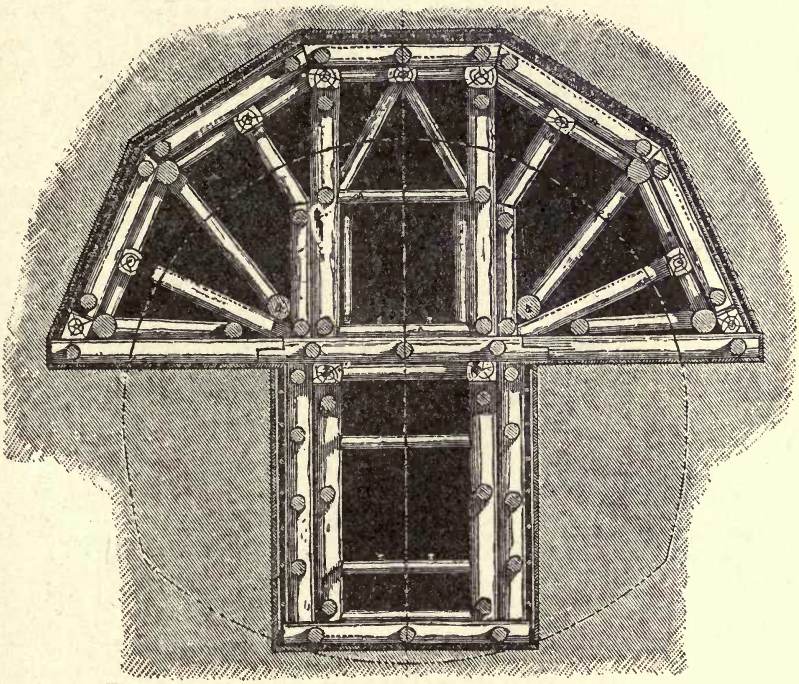


FIG. 23a.—Austrian System; Arch Area Enlargement.

or wooden voussoirs, well jointed and connected, carried upon longitudinal wall plates resting upon posts, the latter either with or without a sill.

In the earlier, and in some of the later Western American tunnels, this timber lining was lagged and left in place, well packed outside with broken stone. This was simply a measure of original economy of construction, as the rotting of the tim-

bers and the danger from fire sooner or later demanded a more permanent lining of brick, stone or concrete.

A simple application of the American system of timbering is here shown in an illustration of the Little Tom tunnel, on the Norfolk & Western Railway, built in 1888-90. The material penetrated was a gray sandstone, in approximately horizontal beds, and cut at times by the coal seams of that section. These rock beds varied in thickness from a few inches to sev-

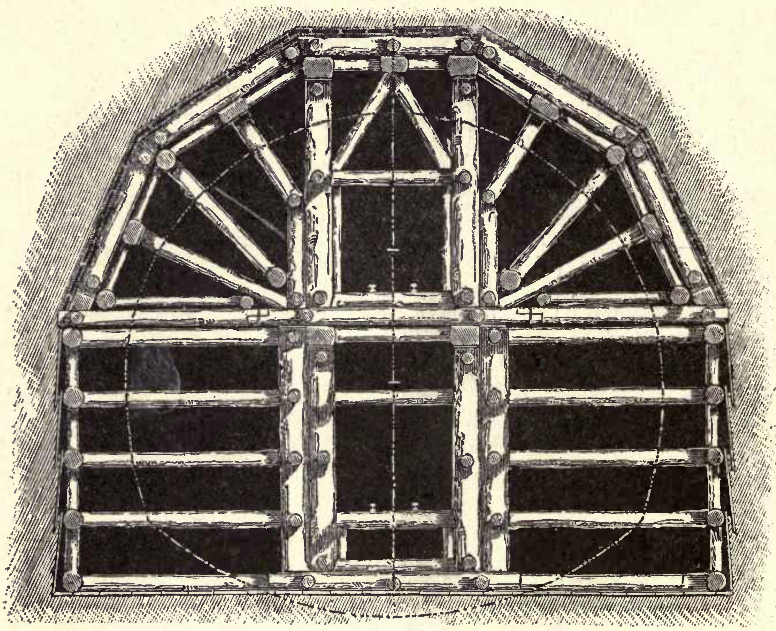


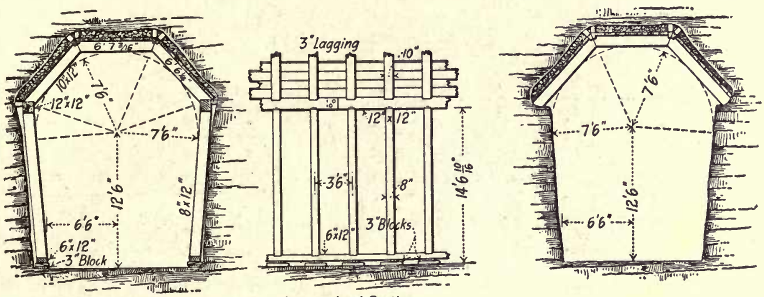
FIG. 23b.—Austrian System; Section Completely Excavated.

eral feet; and the rock itself disintegrated upon exposure to the air, and thus required ample timbering.

The dimensions, location and form of the timbers are shown in Fig. 24. The wood used was first-class white-oak, and originally it was left in the tunnel as a protection against falling rock during the early operation of the road. Where the rock was comparatively sound the three roof-segments were alone used, supported in "niches" cut in the rock; but as a rule

the 3-inch lagging shown was laid on these segments, forming a continuous protection.

In a letter to *Engineering News,** Mr. Emile Lowe, C.E., gives the cost of this work as follows: The amount of timbering per lineal foot approximated 250 feet board measure. A part of this timbering was done by day labor, and the remainder under a contract of $60 per thousand feet board measure. The timbering actually cost about $15 per lineal foot. The area of the rock section was 263.66 square feet, equivalent to 9.765 cubic yards per lineal foot. The area of the timbered section



Cross Section. Longitudinal Section.

FIG. 24.—American Tunnel System: Little Tom Tunnel, Norfolk & Western Railroad.

of the tunnel was 314.16 square feet, or 11.635 cubic yards per lineal foot. The contract price for excavation was $3.50 per cubic yard; so that the respective costs of the two sections for excavation were $34.17 and $40.72 per lineal foot. Some allowance was made for breakage outside of the theoretical section of the tunnel, and for this outside work the contractor was allowed $1.50 per cubic yard. Stone packing over the timbers was paid for at the rate of $1.50. The total cost of the tunnel was thus about $115,000, divided about as follows in relative cost:

Excavation, per lineal foot	$43.00
Timbering, per lineal foot	16.00
Packing, per lineal foot	1.00
Total cost per lineal foot	$60.00

**Engineering News*, April 19, 1900.

This tunnel was driven partly by hand and partly by machine drills; and the daily progress ranged from 2 feet to 6 feet in the heading, and from 2 feet to 4 feet in the bench.

Driving Through Loose Gravel.—A good example of the American method of driving a tunnel through loose gravel is here taken from an article on the tunnel on the Crow's Nest Pass line, Canadian Pacific Railway, written by C. R. Coutlee, C.E., of Vancouver, B. C.*

This tunnel was only 900 feet long, but it passed through a loose and comparatively dry gravel for its entire length. The

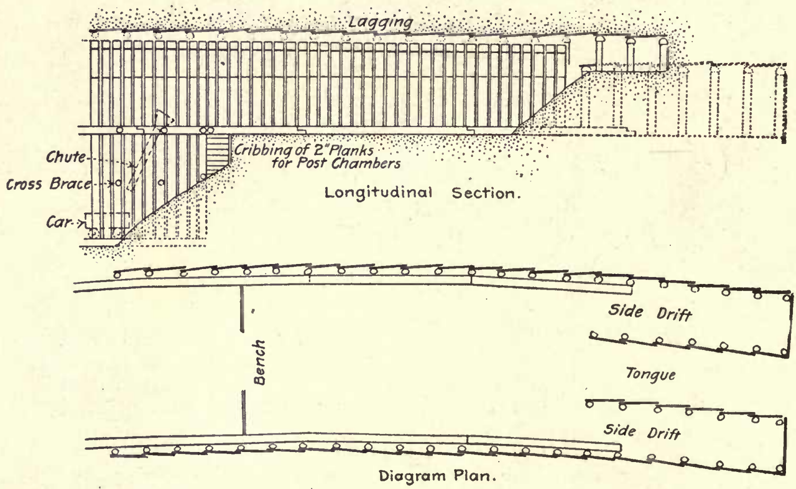


FIG. 25.—Crow's Nest Pass Tunnel; Longitudinal Section and Plan, Showing Method of Driving.

method adopted for driving was practically as follows, the dimensions of the tunnel being indicated on the accompanying illustration (Fig. 26):

In the arch area of the tunnel two side drifts, 8 feet high and 6 feet wide, were driven, leaving about 8 feet of material between them. The frames of these drifts were made of 8-inch round mountain fir. A sill-piece 6 feet long was first set accurately to the elevation of the under side of the wall plate; on

*_Engineering News_, April 2, 1903.

this were set up the posts; and the cap, 4 feet long, was flatted and gained down 1 inch upon the posts to form a small shoulder and prevent squeezing in.

With the drift-frame in place the face in front was walled with 1-inch breast-boards, braced with inclined struts. All around the outside of the frame close lagging was entered and driven forward by sledges. This lagging was made of 2 x 4-inch mountain fir, in 5-foot lengths. Each piece was first driven about half way, with an upward and outward lead, making as close joints with its neighbor as possible. With a 2-foot hood thus secured, the miner carefully removed the top breast-

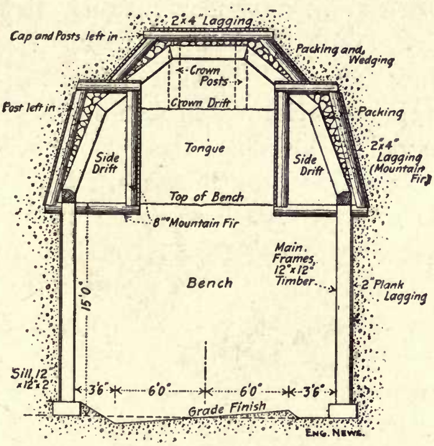


FIG. 26.—Transverse Section; Showing Method of Excavating and Timbering.

board, and was met with a flow of gravel. But he stopped this flow by pushing the board ahead about 2 feet and wedging it in place. The next board was removed and pushed forward in like manner, and the operation was repeated until the whole breast of the drift had been advanced about 2 feet.

As the advanced lagging was subjected to side and top pressures, and only held by the precarious support given by the breast-boards advanced, to secure a better support a false frame of lighter timber was now set up. With the latter in place the lagging was driven forward its full length, and the breast-

boards were separately advanced as before; and finally a second true frame was erected about 4 feet from the first one.

The almost fluid pressure of the gravel was too great to allow the insertion of a new set of lagging to wedge out the lagging already in place. But the upward and outward flare given the lagging brought the points about 4 inches outside the second frame. This space, outside the posts and cap, was bridged by 2-inch scantling, blocked off from the frame by 2-inch blocks; and beneath this bridge the new lengths of lagging were driven. As it was, considerable friction was encountered.

After the side drifts had advanced about 20 feet, the top-heading was driven in a similar manner, though this was only 4 feet high, and the 8-foot cap required a middle prop. This top-heading connected the side drifts at the top; the top lagging of the side galleries was broken through, and the block arch of five 12 x 12-inch timbers was set up on the wall plates, the latter being also 12 x 12-inch sticks, shaped on top to fit a "crow-foot" or V-shaped notch on the arch timber, and bored at 15-inch intervals for dowels. At each joint of the arch $\frac{3}{4}$-inch round iron dowels, 6 inches long, were inserted. In this tunnel the arch sets and vertical posts were placed only 3 inches apart.

As the lower bench was excavated the two sides were breast-boarded with 2-inch plank; but the central part was allowed to assume a slope. Round, 6-inch timbers were placed horizontally, as the digging progressed, across the tunnel at the level of the wall plates and at 5-foot intervals; and another tier of the same bracing was located 7 feet lower down. Against these struts the lower boarding was braced.

In excavating the post-chambers the top breast-board was removed and the gravel scraped away sufficiently to allow this board to be set forward 3 feet. A side-board was then inserted parallel to and just outside the wall plate to prevent side-runs. In this manner a chamber was cribbed down to grade at each side; and at grade a 12 x 12-inch sill 2 feet long was set. A post was then entered under the wall plate and resting

on the sill, and the bottom of the post was pushed outward by a jack until the post was plumb. Great force was required to do this, but a tight fit was secured.

While excavating the post-chambers the unsupported wall plate formed a bridge, about 3 feet long, from the gravel of the bench to the posts already in; the drift-frames assisted in holding up these plates. When the ground would permit it, a space for two posts was excavated at one time.

At this tunnel an advance of about 21 feet per week was made, and the cost amounted to about $77 per lineal foot for labor, timber and supplies. The timber lining was left in the tunnel permanently.

Crutch System.—The Lake View tunnel, under Lake Michigan at Chicago, Ill., is two and two-thirds miles long, and it was driven through different grades of clay, with occasional pockets of sand. The standard section was circular, 8 feet and 10 feet in diameter inside.

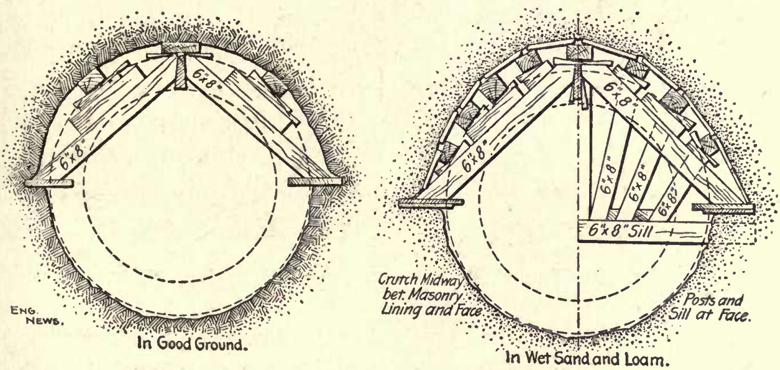


FIG. 27.—The Crutch System of Tunnel Driving.

Owing to excessive excavation resulting from methods previously followed, Mr. Paul G. Brown, engineer in charge, adopted the so-called crutch and crown-bar system of timbering, here shown in Fig. 27.

In this system horizontal wall plates were first let into the sides of the excavation about on the line of the horizontal diameter. Upon these plates rested pairs of 6 x 8-inch timbers, form-

ing inverted V's, with the apex supporting a longitudinal timber. Upon the outside of the V's, or crutches, blocking was placed to hold other longitudinals supporting the sides. The number of these latter timbers varied with the character of the soil.

A 6 x 8-inch sill was placed at the face, and the face was bulkheaded to form a bearing for the sill. One set of crutches

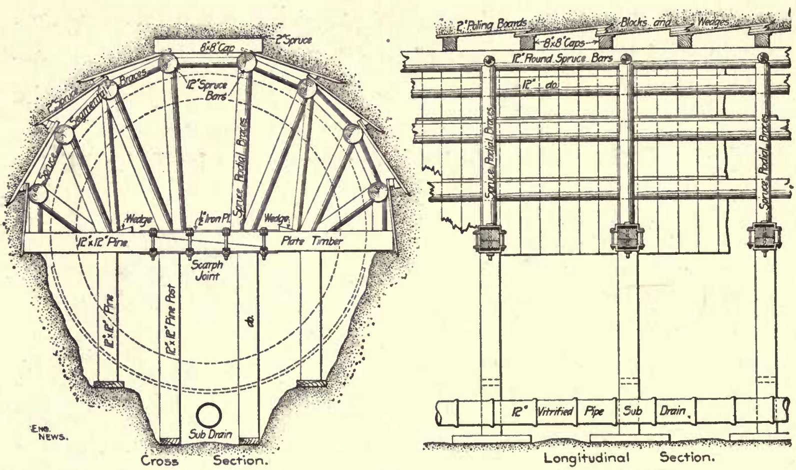


FIG. 28.—Tunneling Through Sand: Brooklyn, N. Y.

was used to support the bars, midway between the face and the finished masonry, the rear end of the bars being carried by the masonry, and the front end by posts at the face. All of the timbers were set up by wedges. The progress made was about 14 feet per day; costing \$24.41 per lineal foot in clay, and \$38 in rock.

Timbering a Sand Tunnel.—The timbering here described was used in building a circular sewer, 13 feet 6 inches clear diameter, in Brooklyn, N. Y.; the work was designed by, and was executed under, the direction of Henry R. Asserson, Chief Engineer of Sewers. This sewer tunnel was lined with 16 inches of brickwork, with a granite block invert. The tunnel was driven through fine sand carrying considerable water. This sand would not stand up during excavation, but was hardly

unstable enough to be classed as quicksand. The work was carried on from two shafts.

In excavating this tunnel (Fig. 28) a drift 6 feet wide and 7 feet high was first driven at the bottom center of the section. The primary purpose of this drift was to drain the sand, and to facilitate this a tile sub-drain was laid about 2 feet be-

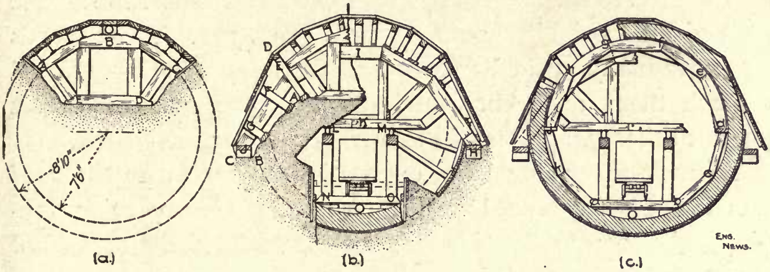


FIG. 29.—Meem Poling-board System.

low the bottom of the invert and left in place. Almost simultaneously with the bottom drift, another drift was driven at the top of the section, 8 feet wide and 7 feet high; and both drifts were kept about 50 feet ahead of the full section work. As they were driven, these drifts were held by the usual frame and

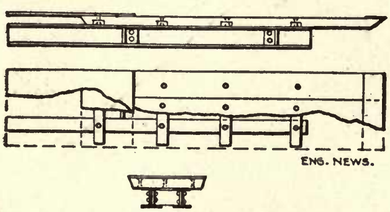


FIG. 30.—Detail of Meem Poling-board.

poling-boards, with the face bulkheaded and held up by struts, or rakers.

The section was enlarged from the heading by excavating on each side, inserting the roof-bars, radial struts and poling-boards one after the other, as shown in the illustration. The radial struts were removed as the lining was built; but all other timbering was left in place, with all the interstices filled with concrete.

Meem Poling-board Method.—For another sewer tunnel in Brooklyn, driven through the same water-bearing fine sand, Mr. J. C. Meem, C.E., devised the plan here shown in Fig. 29.

In this method a top-heading was first taken out, embracing about one-quarter of the perimeter of a circular section 17 feet 8 inches diameter. The segment guide-frame *A B C D E* was then erected, and over the top of this was slipped the ends of five special iron poling-boards (Fig. 30). These boards were gradually pushed forward as the excavation progressed beneath them, and other guide-frames were successively set up, until there were five of these frames under the boards.

To next carry down the excavation on each side the roof was temporarily braced by the struts *E F G* supporting lagging. As soon as the side cuts were completed the segmental

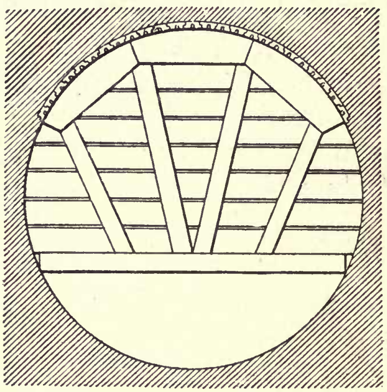


FIG. 31.—Iron Crown-bar System of Tunneling.

frame *H I J K* was set up, and struts were inserted to relieve the poling-boards and temporary timbering. The excavation was carried on down the sides by lagging and radial struts, until the section had been sufficiently opened to permit the building of a portion of the invert. The timber frame *L M N O* was then built, and the weight of the segmental timbering was transferred to the invert. The excavation was now ready for the completion of the lining masonry. To build this masonry segmental centers were used, with the frames erected

between the timbering sets, the latter being removed as the masonry progressed.

As shown in the cut, the poling-boards used at the top have steel-shod cutting edges and a steel-plate tail-piece with small I-beam stiffeners beneath. In operation the tail-piece overlapped the roof-lagging. The poling-boards were driven ahead by 30 and 60-ton hydraulic jacks, operated by a hand pump. The face of the heading was generally kept about 30 feet ahead of the brickwork.

Iron Crown-bar System.—The King's Cross Station tunnel, driven in 1890 in London, England, is only 1,590 feet long,

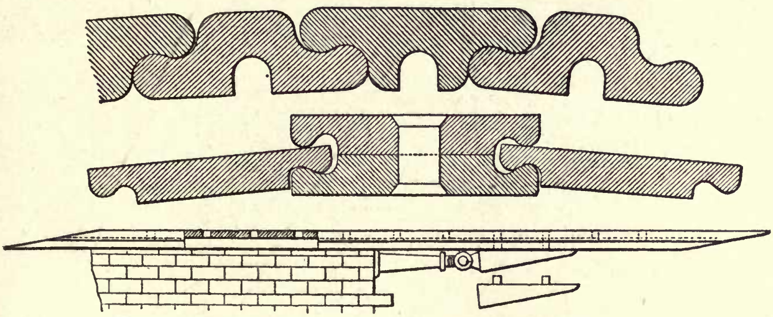


FIG. 31a.—Needles Used in Iron Crown-bar System.

but it passes under the Regent's Canal, with only 6 feet of earth above the tunnel at some places. The tunnel is generally circular, with a clear diameter of 26 feet, and is lined with brick throughout.

In this case—and especially to reduce the head room required by timber—the ordinary timber crown-bars were replaced by a series of iron and steel "needles," grooved longitudinally so that the bars link together and yet have sufficient play to allow them to take the form of the arch. As it was difficult to roll the double-needle, two ordinary needles were joined by countersunk rivets, as shown in Fig. 31a.

The needles here used are 10 feet long, 6 inches wide and 2 inches deep. As soon as the brickwork is built under their protection, the needles are pushed forward in sets of

three, until only one or two feet of the needles rest upon the brickwork; and as the needles are pushed forward by screw-jacks, they are held up by successive segmental frames of the ordinary type. To facilitate the forward motion of the needles, holes are drilled at intervals along each needle; into these holes the two bosses of a bracket are set, and against this bracket the screw-jack pushes.

Crown-bars of Old Rails.—The Marsden tunnel on the London & Northwestern Railway, in England, was driven, in 1893, by the English method of timbering. Wooden crown-bars were used in part of the tunnel; but, to decrease the amount of excavation and packing, Mr. A. A. Macgregor, Resident Engineer, suggested the method described in Fig. 32.

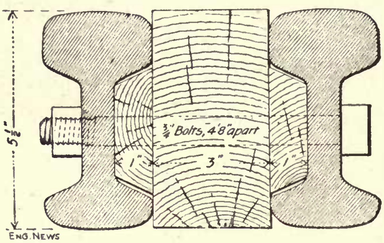


FIG. 32.—Crown-bar of Old Rails.

To each side of a 3 x 5½-inch timber he through-bolted two 75-pound bullhead steel rails, worn out in service. The crown-bars thus made were cheaper than the all-timber bars, saved one-half or more in excavation and packing and were easier to handle. Tests made showed that this crown-bar was equal in strength to a round larch bar 11 inches in diameter, under similar conditions of loading.

The chief objection to the rail-bars is their stiffness. Their maximum deflection is about one-half that of the larch bars; and they are somewhat treacherous and have to be carefully watched against undue stress. They do not give warning by bending to the same extent as the all-wood bar.

Steel-lined Tunnel.—While not properly coming under the head of tunnel timbering or driving, the tunnel here described

is sufficiently curious to be noted. In the Cripple Creek mining region it was necessary to extend the line of the Golden Circle Railway through the dumping ground of the Portland mine; and to meet the conditions a steel covered way was constructed which would be gradually converted into a tunnel by the operation of dumping the waste from the mine.

This way was 242 feet long, 14 feet wide inside, 10 feet high to the springing line, and was roofed with a semicircular arch of 7-foot radius. It was made of steel posts and arches resting on soft cast-iron piles. These piles were hollow, 12 inches in diameter outside and 1 inch thick; they averaged 8 feet in length and were spaced 8 feet between centers. The point of the pile was solid for half its length and a timber core was used in driving them. After the tops had been cut to a level by pipe-cutting machines, a cast-iron cap was put on each pile; and on these caps, on lead plates, were laid two sets of 12-inch 31-pound longitudinal I-beams. The calculated load on each pile was 56 tons; and the pile foundation cost $7 per lineal foot of tunnel.

Each post was made of two 12-inch 31-pound I-beams, having a bearing surface of 12 x 14 inches on each pile; the posts being spaced 2 feet apart, center to center. Attempts were first made to bend the tops of the posts so as to form a half arch. But this failed, and each half arch was made of web and angles in three 4-foot sections, spliced with $\frac{3}{8}$-inch plates; a $\frac{1}{2}$-inch plate was used for a connection with the posts.

For lateral bracing an 8-inch I-beam crosses under the track and connects the longitudinals at each set of piles. At the top of the arch another 8-inch longitudinal ties each arch to its neighbor, and 8-inch channel irons connect the sets at the springing-lines on each side and outside the posts. The roof covering and siding is made of 3-inch red spruce timber; but as this rots away it will be replaced with two rings of brick.

The cost of the steel work and planking amounted to about $50 per lineal foot of tunnel, in 1898.

Sand-chamber and Caisson Method.*—The Meudon tunnel, on

**Engineering News*, Sept. 11, 1902.

the new line between Paris and Versailles, was completed in 1902, after encountering difficulties which were surmounted in the following manner:

The tunnel penetrates a marl formation overlaid by water-bearing sands. Work was commenced with a Clichy-type of

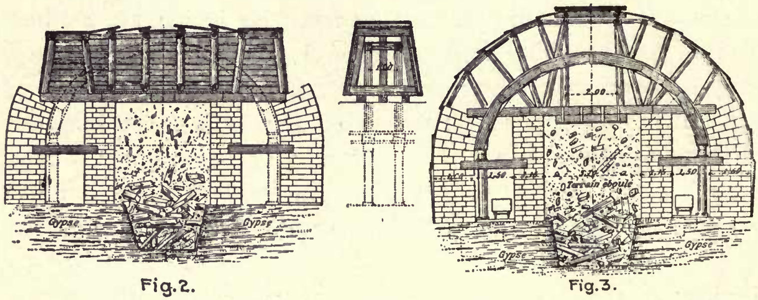


Fig. 33.—Meudon Tunnel: Sections Showing Temporary Interior Walls, and the Transverse Gallery at the Point of Commencing Attack on the Debris near the Top of the Tunnel.

shield; but this was soon deformed and heavy and careful timbering was resorted to. At one point the marl very closely approached the sand; the marl swelled on exposure to the air, and water finally broke through from above, and a serious cave-in occurred when only 115 feet of the side walls remained

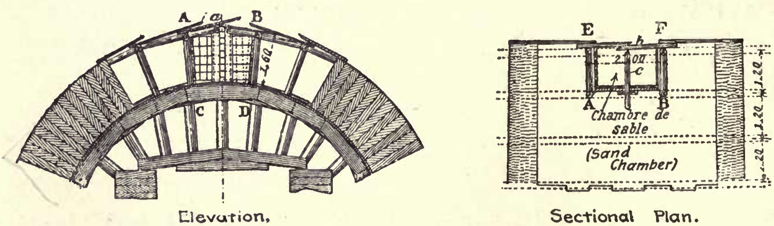


Fig. 33a.—Meudon Tunnel: Detail Showing the Construction of a "Sand-chamber."

to be built. The difficult work lay in tunneling through this mass of marl, sand, water and broken masonry.

The first operation was to build strong masonry bulkheads across the tunnel to confine the cave-in, leaving small passages through these bulkheads that could be quickly closed. Then a

small gallery was driven outside the masonry standing, with the view of draining the cave down grade toward Paris.

Two temporary walls were then built inside and parallel to the axis of the tunnel to better support the arch-centers, and this was done in ordinary drifts and without great trouble. (See Fig. 33). The Versailles end of the cave was soon reached; and as the central part of the mass was relatively free from quicksand, a cross-heading was driven through it and

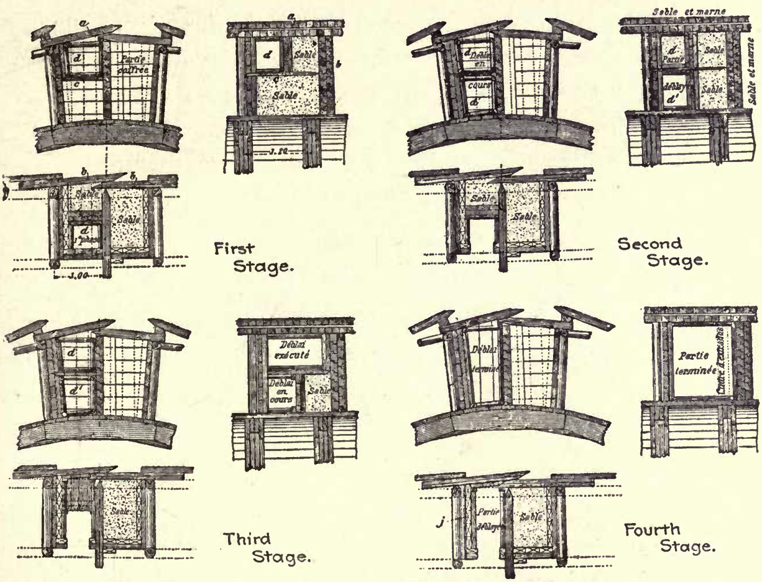


FIG. 34.—The Four Successive Stages of Emptying a Sand-chamber: a = roof of pieces 13x13 cm., raking and jointed; b = transverse poling-boards 13x13 cm., with a jog; c = horizontal pieces 6x18 cm.; d = advance poling in pieces 20x25 cm.

centers were erected upon the temporary longitudinal and the side walls for building the arch. But the building of this arch proved to be a long, difficult and costly operation. The fine sand, carrying water, was almost fluid; the use of compressed air was impossible owing to the enormous water pressure, and the freezing process could not be resorted to, owing to the impossibility of driving pipes horizontally through the broken arch masonry imbedded in the sand.

In this emergency the engineers devised the "sand-chamber" method (Fig. 34). The advance was made in a concave form and maintained by a system of small boxes formed with poling-boards, completely stopping off the face. This was done by forcing forward, for sides and roof, a series of 6 x 6-inch squared sticks, as closely jointed as possible and sometimes caulked. The size of these chambers never exceeded one cubic metre in volume, and in each the face was bulkheaded. The 6 x 6-inch timbers were forced through this bulkhead by 30-ton hydraulic jacks, by first boring holes around a place 6 inches square and then forcing the enclosed block ahead of the timber. To decrease the hydraulic pressure encountered, the timbers were sometimes bored on their axis, thus permitting the sand and water to flow through the sticks as these advanced. Finally the pressure became so great that beams (Fig. 35) 6 x 6

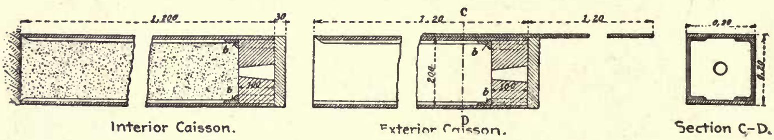


FIG. 35.—Detail of Metal Beams, or "Caissons," at Versailles End.

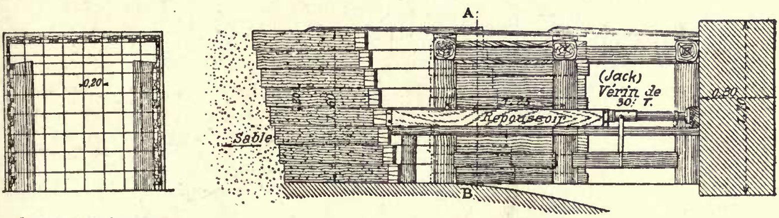
inches, outside, were made with two channel bars and two plates. These iron beams were open at the forward end and closed at the rear, with an opening in the plugged end that could be closed if necessary.

After each main chamber had been divided by the above described means into four secondary chambers of not more than one cubic yard capacity, each new chamber had to be emptied of sand and the bulkhead pushed forward. This was very slow and dangerous work, and it is only necessary to say that to empty one chamber, or to take out a little over one cubic yard of sand, required one week's time.

When the arch work thus constructed approached within 6½ feet of the crushed end of the standing arch, a metallic roof was pushed forward from the top of the advance gallery to the top of the arch still in place. This roof was of so-called iron

"caissons," 6 inches square and 10 feet long, pushed forward by 70-ton rams (Fig. 36).

Though the new arch throughout the renewal was 5.24 feet thick, water filtered through it owing to the enormous pressure. To stop this a waterproof tunnel lining was put in. A steel sheet lining 1mm. thick, was made into a ring 1m. wide by soldering the joints, and these rings were also soldered together. This sheet lining was secured to oak pegs driven in holes drilled in the masonry, and a space of about $1\frac{1}{2}$ inches was left between the lining on the masonry, which was filled by injecting cement mortar. To hold this steel shell against the outside pressure a concrete steel lining was put inside of it and secured to bolts passing through the steel shell to the masonry This concrete steel lining was about 13 inches thick at the



Cross Section A-B. Longitudinal Section.

FIG. 36.—Method of Using "Caissons," at Versailles End.

crown, 9 inches at the spring and 11 inches thick at the base, and imbedded in the concrete was a network of round longitudinal, transverse and diagonal rods, of varying diameters.

Pilot-tunnel System.—This system was first devised and used at the old Hudson River tunnel by Mr. John Anderson, general manager for the contractor. It was later successfully employed by the contracting firm of Anderson & Barr in building a section of the Brooklyn relief sewer, 10 to 15 feet diameter, running through fine sand and loose, dry gravel.

The pilot-system is especially devised for tunneling through soft and uncertain material, the pilot itself furnishing a support for holding the roof, as well as the centering for masonry.

The "pilot" is a cylinder, usually 6 feet in diameter, made up

of curved plates of boiler iron riveted on the four sides to light angle-irons pierced with holes for bolts. The pilot is located on the axis of the tunnel (See Fig. 37) and the segments are bolted up, commencing with the roof-plates, as the excavation is made from within the pilot, which is thus pushed forward and kept about 30 feet in advance of the completed section. The rear end of the pilot is supported by timbering, and the cylinder itself acts as a truss over the short invert space.

In operation the material is carefully removed from about

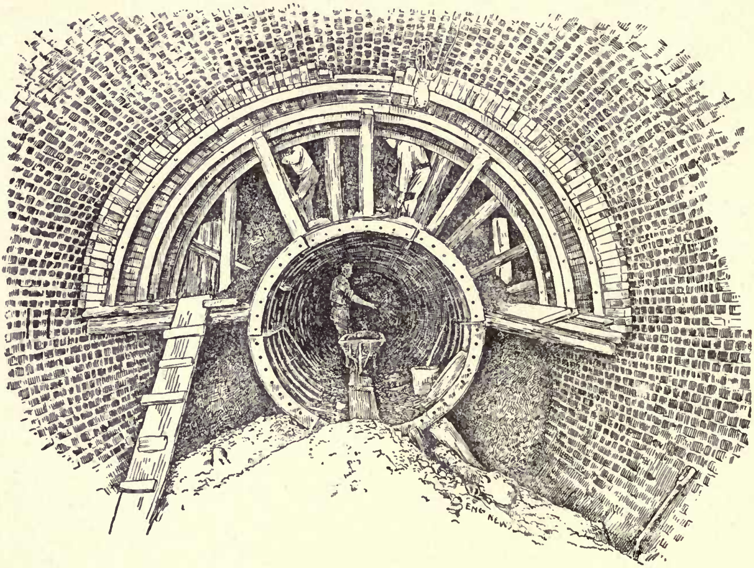


FIG. 37.—The Anderson Pilot-tunnel System.

the center-plane of the pilot; the material in the roof and sides being held up by an outer plate-iron shell, made of flanged segments and supported by radial struts abutting upon the shell of the pilot tube. The masonry lining is put in place by setting up ribs of T-iron, curved to fit the intrados of the arch and with allowance made for the lagging. These center-ribs are also supported by struts leading to the pilot, and the roof-struts are removed as these are put in place. In putting in the outer shell-plates, work is commenced at the top and the material is

held back by light poling-boards until the plates can be bolted to the completed shell. This outer shell, which is extended over one-third, or a little more, of the perimeter of the tunnel, is left in place.

Sewer Tunnel in Quicksand.—In building a sewer in Rochester, N. Y., the contractor found it necessary to drive a 500-foot tunnel through quicksand. W. D. Lockwood, M. Am. Soc. C.E., describes as follows the method pursued:*

The heading was only 6 x 6 feet and this was timbered as shown. In the breast a center leg was sometimes employed, and in other cases a false cap and raker was put in, tying up the completed work with stretchers.

The sets were placed about 4½ feet, c. to c., using 8 x 8-inch hemlock, with 6-foot oak lagging, 2 inches thick on the top, and 2-inch hemlock lagging on the sides. Two miners in the

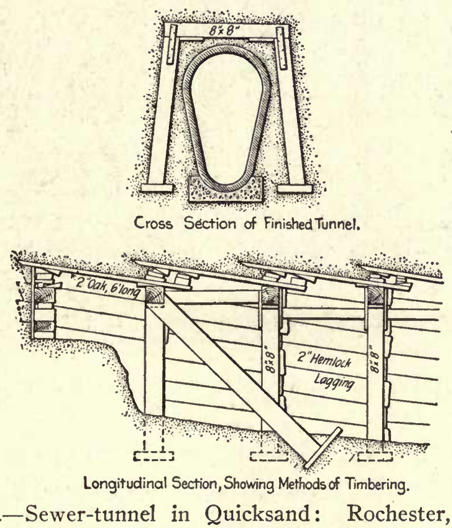


FIG. 38.—Sewer-tunnel in Quicksand: Rochester, N. Y.

breast and two muckers constituted the working force, and the average progress made was 4½ feet per shift. The miners were paid $2.50 per day and the muckers $2.00. The work of driving and timbering the tunnel complete cost $5 per lineal foot, $3 of this being for labor.

*_Engineering News,_ Feb. 21, 1895.

Dry Sand Tunneling.—Dry sand will run almost like a fluid; and as a consequence tunneling through it is slow and dangerous work, requiring the utmost care and patience in timbering to prevent a run of sand. Small, loose, dry gravel acts in much the same way.

In the case of a large sewer tunnel through very dry sand, built some years ago in Brooklyn, the sand flowing into the excavation undermined adjoining houses, and the job was abandoned by several contractors in succession. The then firm of

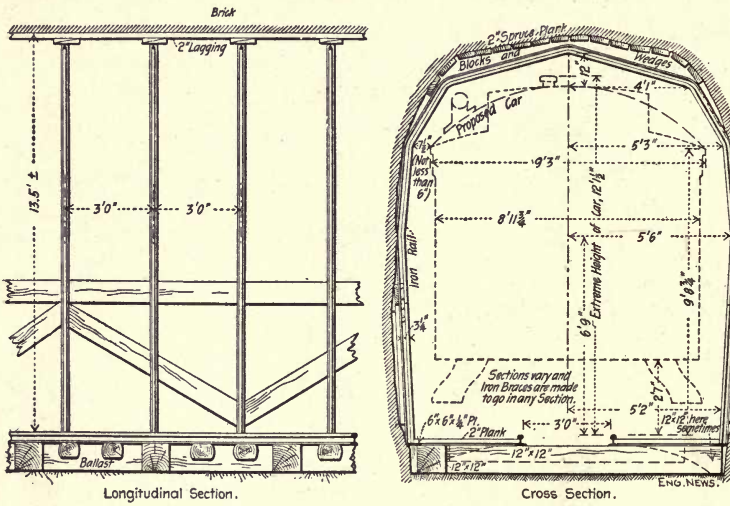


FIG. 39.—Temporary Bracing of Old Tunnel.

Anderson & Barr, of New York, carried out the work successfully as follows:

A connection was made with the city water distribution system, and a large pipe was carried into the tunnel and near the working face of the tunnel. To this water pipe was connected by a flexible hose a section of 2-inch pipe, about 16 feet long, plugged at the end and perforated at the sides for a length of about 10 feet. By means of this simple apparatus the dry sand in the advance heading was made wet enough to stand during excavation; and a wall of wet sand was thus continually kept between the dry, running sand and the finished tunnel.

Enlarging Tunnel in Soft Ground.—In 1894 the Boston, Revere Beach and Lynn Railroad Company was forced to replace an old and narrow single-track tunnel by a twin tunnel adapted to the requirements of modern traffic. The old tunnel was 471 feet long, $12\frac{1}{2}$ feet wide and 14 feet high in the clear, and the material penetrated by it was a clay hardpan of a treacherous nature. Mr. George M. Tompson, M. Am. Soc. C.E., Chief Engineer, devised the plan of reconstruction here briefly described:

Though the three-ring brick arch of the old tunnel had been badly squeezed out of shape by the ground pressure, it was determined to build the new north tunnel parallel to the old

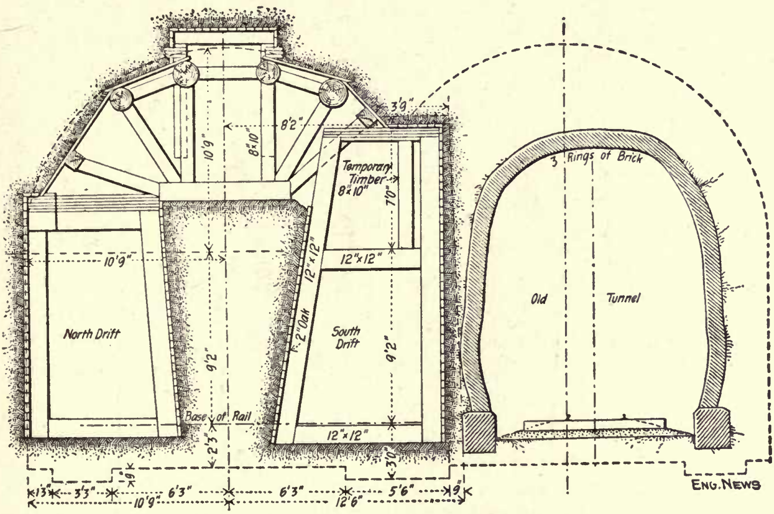


FIG. 40.—Section of New Tunnel Excavation, Showing Drifts and Bracing.

tunnel, complete the new tunnel and turn the traffic into it while building the new south tunnel.

The old tunnel was first braced up with old rails bent to form as shown in Fig. 39. This work was done at night, and the upper sections were forced and held up by a hydraulic jack placed on a flat-car, while the men were bolting on the leg sections. The whole form was then lowered to a bearing and lagging was driven in to fill the space between the iron rails and

the brickwork. To provide clearance this frame had to be sunk into the brickwork in some places.

The new tunnel was commenced from shafts sunk near each end, and the material was found to be badly ruptured, requiring the heavy timbering shown in Fig. 40. Work was commenced at each end at the top of the high side or south drift, and carried down 3 or 4 feet by driving sheeting and poling-boards. The short temporary timbers were put in and the drift was closed by a bulkhead to prevent caving. The excavation in this drift was then carried down to a point just below the base

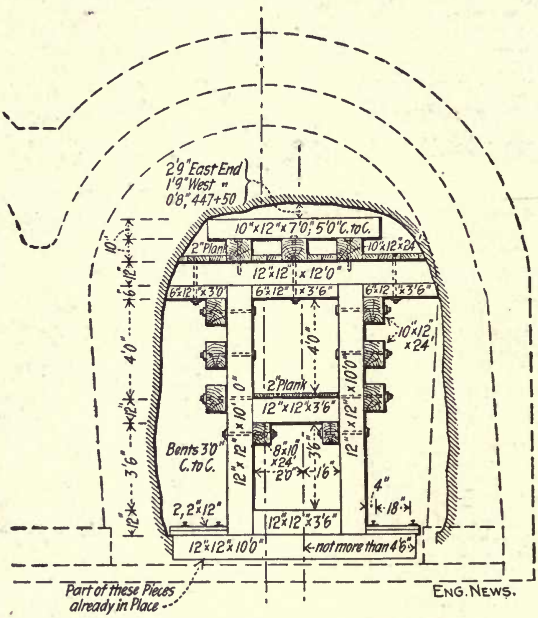


FIG. 41.—Timber-core Used in Rebuilding Old Tunnel.

of the rail and the long side timber was set. The north drift was then driven and timbered, and the arch area was enlarged from the upper central drift shown. The timber sets were spaced 3 feet, c. to c.

After the north tunnel had been completed, a heavy timber center platform was built (Fig. 41) to replace the earth core used in the new tunnel and not removed until the arch had been

built. A drift was then run over the old brickwork and the arch was broken through from above. The new lining was five rings thick.

Sewer Tunnel in Sand.—In connection with the construction of the New York Rapid Transit Railway a sewer tunnel had to be driven under Chatham Square. The depth below the surface

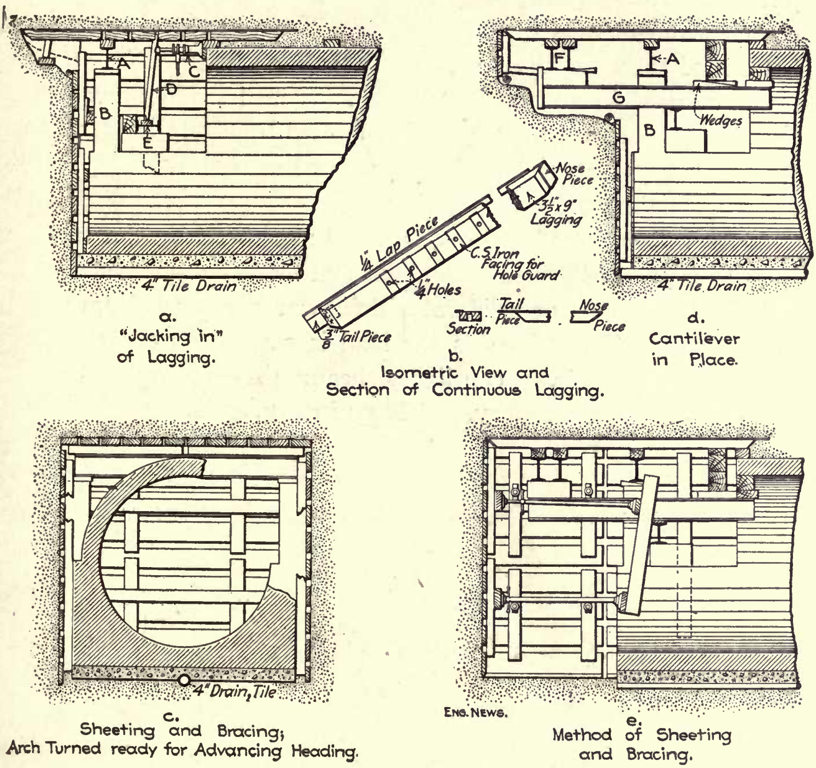


FIG. 42.—Chatham Square, New York: Driving a Sewer Tunnel Through Sand.

was only 30 feet, and the street traffic was heavy above the tunnel. The material was a fine running sand.

In driving this tunnel, 6½ feet diameter, several novel devices were made use of which may be summarized as follows:

(1) The use of a system of interlocking poling-boards to support the roof, and the driving of these boards by ratchet-

jacks. (2) The use of a cantilever beam to support the forward ends of the poling-boards. (3) The support of the sides and front of the excavation by lagging boards laid flat against and over strips of canvas, the latter being rolled down as the excavation progresses.

The poling-boards were made of $3\frac{1}{2}$ x 9-inch lagging, with a 3 x $\frac{1}{4}$-inch steel strip lapping with half its width over the adjacent board and thus closing the space between them. In the bottom of these boards a series of openings, guarded by cast-iron, are used in pushing the boards forward. The power to perform the forward movement is supplied by a ratchet screw-jack, acting upon the board by means of a vertical lever, and reacting against the masonry lining.

In operation these boards are pushed ahead one by one, until they have been extended their full length. When pushed forward there is a very considerable downward pressure from the earth above. To resist this the load is carried on transverse I-beams carried by a cantilever beam system, wedged up against the lining masonry, as shown in Fig. 42-e.

CHAPTER VI

TUNNEL ARCH CENTERING

Requisites of a good arch-center—Manner of framing centers—Adjustable and moving centers—Steel-rib centers—Concrete-forms for small tunnels—The placing of concrete tunnel-lining.

After the arch-area has been fully excavated and the roof secured by the necessary timbering, a center, or form, is required upon which to build the final protecting arch masonry. The principles of good center design are: That the completed form has a central opening sufficiently large to permit the passage of material through it; that the center is strong enough to hold the arch and a possible load thrown upon it by the ground above; that it is convenient to set up and take down, with no single part too bulky or too heavy for easy handling, and while it should contain no superfluous material, it should be so designed that it will admit of rapid and effective strengthening when an emergency arises.

In the United States general use is made of the skeleton-rib center. This is constructed, according to span and load, of two, three or more layers of heavy plank, sawed into segments with radial joints and with the outer edges of the planks curved to fit the intrados of the arch, less the thickness of the lagging to be used. These segments are so assembled as to "break joints," and they are firmly fastened together with screw-bolts so as to form a continuous rib. This rib is generally stopped some distance above the true spring of the arch; the first two or three feet of the arch being built up by hand-forms. The object of this is twofold; the weight and size of the rib is thus reduced, and the masonry is more easily started in a clear space. When the center ribs are heavy, the joints are often strengthened by

plate-iron pierced with the necessary number of holes for the screw-bolts.

Fig. 43 shows the standard arch-rib, lagging and supports adopted for the tunnels on the Cincinnati Southern Railway in 1902. The vertical posts are made of 8 x 8-inch stuff set 3 feet apart on centers and they rest on short sills. On the posts is a 4 x 8-inch wall-plate mortised onto the head of the posts, and this wall-plate carries the wedges which support the rib. By "striking" these wedges after the masonry has been laid and the

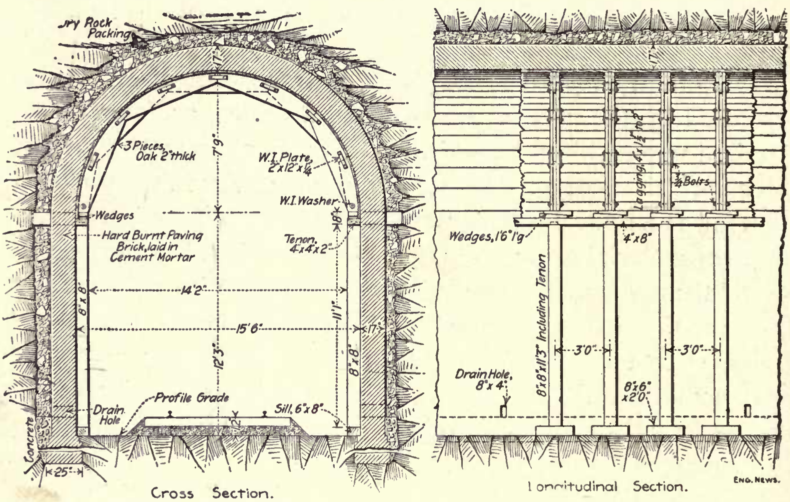


Fig. 43.—Cincinnati Southern R. R. Standard Tunnel Centering.

mortar is set, the rib can be lowered and removed for re-use. In this case the rib segments are held together by iron straps and ¾-inch bolts at each joint. At the springing line on each side, short 8 x 8-inch blocks are fitted between the rock and the wall-plates, at each rib; these are intended to hold the rib and the wall-plate in true position while the masonry is being laid. These blocks are removed with the centers, and the holes are filled up with brick laid in cement mortar.

This centering was built in sections from 10 to 30 feet long, and it was usually "struck" in from four to eight days after the completion of the brickwork lining.

Adjustable or Moving Center.—As before mentioned a number of American tunnels were originally timber-lined, with the view of hastening the completion of the tunnel. In time it is necessary to re-line these tunnels with a more permanent material, and this must be done with as little interference as possible with traffic.

The illustration, Fig. 44, shows the plan adopted for re-lining a 1,410-foot single-track tunnel on the Clinch Valley Division of the Norfolk and Western Railway, this work being

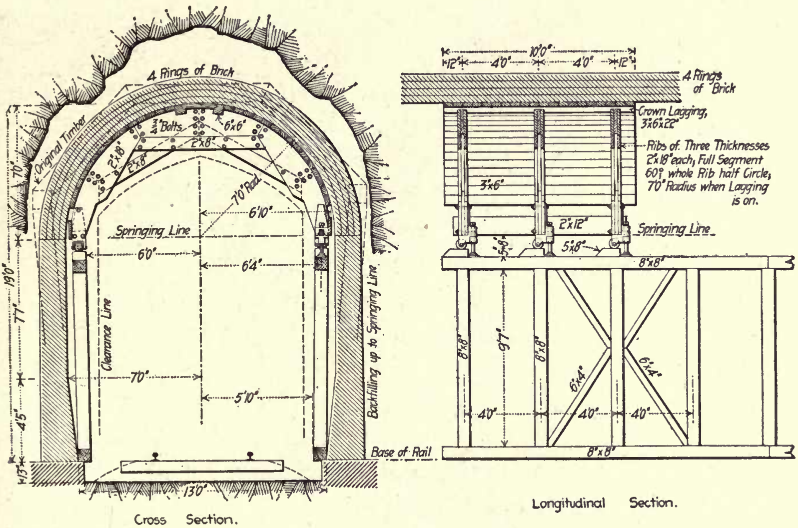


Fig. 44.—Norfolk & Western R. R. Adjustable Centering Used in Relining Tunnel.

done under the direction of Charles S. Churchill, M. Am. Soc. C. E.*

The old tunnel-lining was made up of centers 3 feet apart, located as shown by the dotted lines. It was decided to replace this wooden lining with brick masonry. The rock roof was bad, showing seams or breakage lines extending from 1 foot to 12 feet above the timbering. This dangerous condition made it advisable to remove only a short section of the timber-

Engineering News, March 22, 1900.

ing at one time; and it was also essential to close the opening made as quickly as possible with the brick masonry.

To meet these conditions the movable center was made, as shown in Figs. 44 and 45. Two side trestles, with braced posts, sill and cap, were built to carry the moving centers, and

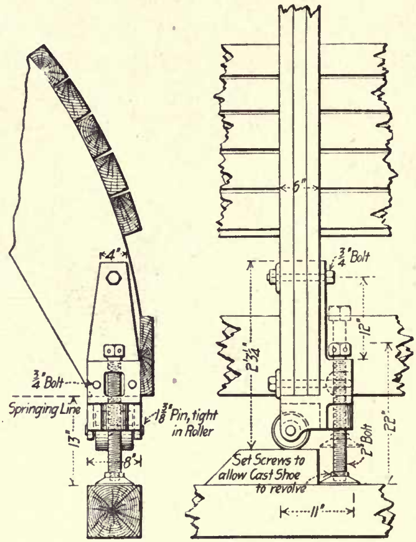


Fig. 45.—Detail of Set-screws and Rollers.

two sections of the trestles and centers were employed alternately. One set was carried ahead and set for the removal of the old timbering, while the masons were laying brick on the other. The centers were moved ahead on the rollers shown in Fig. 45, and they were "set up" and "struck" by means of the set-screws.

In re-lining the Boulder tunnel, in 1893, on the Montana Central Railway, another form of movable center was used and is here shown in Fig. 46. This tunnel was 6,112 feet long and was driven through a seamy blue traprock, and a mass of boulders filled in with disintegrated material. To replace the old timber-lining, granite rubble side walls were built, 13 feet high and generally 20 inches thick, and the arch was a full center of four rings of brick, with a clear span of 15.66 feet at

the spring. Where greater strength was needed the walls were made 30 inches thick and the arch was increased to six rings of brick.

Owing to falls and slips it was impossible to remove all of the old timbering as a preliminary to laying up the side walls. The plan followed was to remove the old posts by first supporting the original roof segments and the lagging and packing

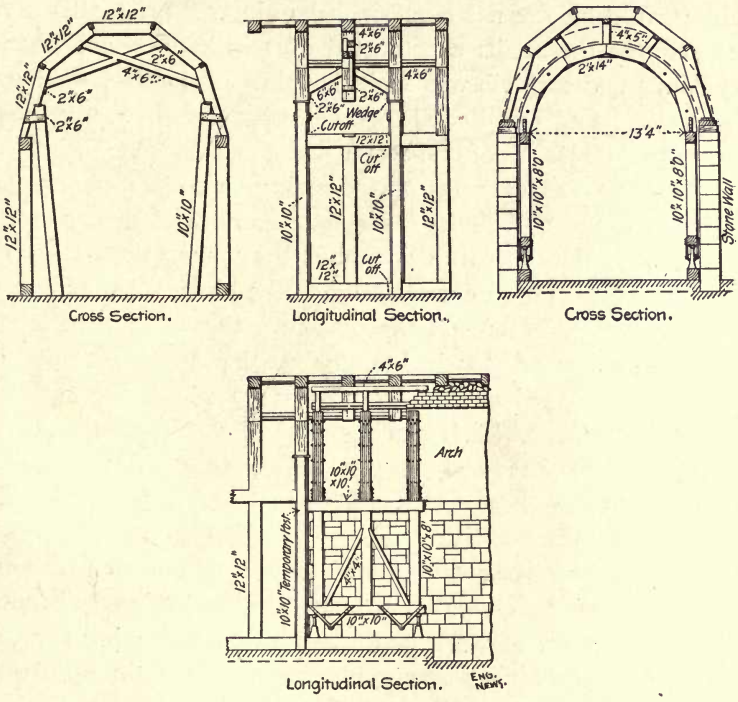


FIG. 46.—Movable Arch-centers; Boulder Tunnel: Montana Central R'y.

above them, by means of the temporary inclined posts shown. In a longitudinal section of four arch-ribs, covering a length of 8 feet, the first and fourth rib were thus supported, and to hold the two intermediate ribs against downward pressure, 6 x 6-inch struts were set up under the ribs longitudinally, and 4 x 6-inch cross struts were put in place to resist lateral movement. The two hip-segments were then sawed off below the connec-

tion with the temporary posts and the old side timbers were removed and the side walls built. Two small derricks—fixed on the flat-cars which brought the stone into the tunnel—were used in laying these walls.

The brick arch was laid on a center running on rollers, on sills laid at the foot of the side walls, this center being fitted with screw-jacks to raise and lower it. This center was $5\frac{1}{2}$ inches less in diameter than the distance between the side walls, thus permitting the use of $2\frac{3}{4}$-inch lagging. Each center was made up of three ribs constructed of 1-inch or 2-inch board segments, and each rib was 10 inches thick and 14 inches deep, the planks being well bolted together. As the ribs were 4 feet apart the total length of one center was about 9 feet.

The arch was built up from the spring on both sides at once, by four masons, and all the space between the arch and the rock was securely packed with dry rubble. As soon as the arch work had been carried high enough to give the hip-segments a bearing of a foot or more on the masonry, these segments were securely wedged and blocked up against the brickwork, and the longitudinal 4 x 6-inch timbers were removed. The arch was then completed, the keying being done by two masons, beginning at the completed end and working back toward the end left "toothed" for the next section of the arch. A staging-car was used in building this brickwork.

A single crew of brick and stone masons completed 8 lineal feet of arch and side walls in 24 hours; the timber and trimming crews were at work at the same time preparing for the brick and stone laying crews. Including an engine and two train crews 35 men were employed in this work.

The Musconetcong tunnel was built in 1872-75, and in 1899 it became necessary to line the portions of it originally left unlined, owing to infiltration of water and unreliable rock. This re-lining had to be done without interrupting traffic, and plans were made accordingly. Owing largely to the unevenness of the rock roof, concrete was adopted as the material to be used; with a minimum depth of 18 inches at the key and 24 inches at the springing line and for the thickness of the side walls.

To facilitate the passing of trains in this double-track tunnel a gauntlet track was first arranged through the tunnel, providing a working space at each side wall. In these spaces a 2-foot gauge track was laid, by using the outside rails of the gauntlet as one of the rails of these tracks. The concrete platform was erected outside the east portal, at the height of a car-floor above the head of the rail.

The traveler used in preparing the roof for the lining was constructed as in Fig. 47, and it ran on two rails laid close to

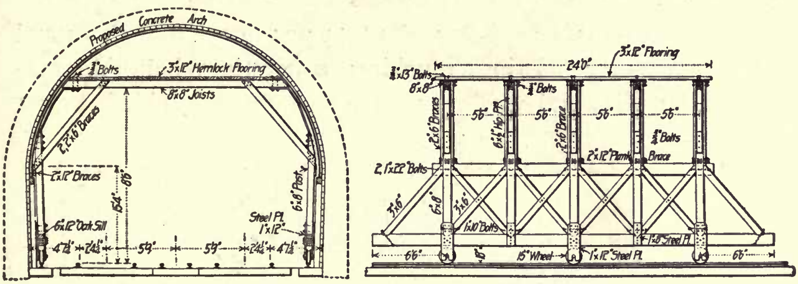


FIG. 47.—Musconetcong Tunnel: Traveling Arch-center.

the side walls. The timber was hard pine, and the wheels were double-flanged. The cross-beam indicated carried the working floor for the men, and was sufficiently high to permit the passage of trains beneath.

To put in the concrete arch the rock roof was hand-drilled and blasted; the sides were blasted out ahead of the traveler, 40% dynamite being used, so as not to shake up the rock any more than was necessary. In the case of heavy roof shots, the traveler was run out of the way and the track was protected by ties. In from 10 to 20 minutes after a shot the track was cleared of all debris and the traffic was never delayed.

The side walls were built by first setting up the temporary posts, then lagging up for a few feet, and depositing the concrete in the space behind. When the concreting had reached the springing lines, and was set, the posts and lagging were removed and thinner posts were substituted; on the latter were laid the wall-plates for supporting the iron ribs and the 2-inch

lagging. These iron ribs were made in halves, bolted together at the crown, and the foot of each rested on a cast-iron sand-box fitted with a screw plug. A 16-foot section was concreted at one time at the sides, and a 10-foot section at the roof. As the arch concreting approached the crown, stiff struts were put in between the ribs and the rock roof to keep the sides from rising at the key, owing to the heavy load on the haunches. Where the drip of water from the roof, or the flow of water from the sides, was heavy, a 3-inch pipe was buried in the concrete extending clear through to the rock.

The cost of this re-lining was $54 per lineal foot of tunnel lined, including blasting, mucking, concreting, handling materials, supplies and workmen. To this must be added $29.91

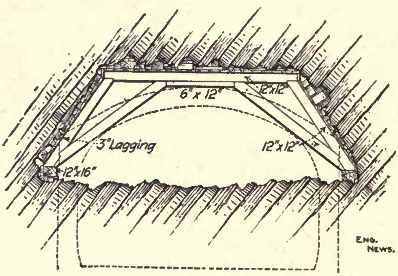


FIG. 48.—New York Subway: Method of Roof-timbering.

per lineal foot for a charge for temporary spur, gauntlet track, shanties, platform, train service, etc., making a total cost of $83.91 per lineal foot of tunnel lined.

In placing the concrete lining in the New York Rapid Transit tunnel, traveling forms and centers were used as shown in Figs. 50, 51.

The general section of the tunnel, and the method of timbering the roof in the Park Avenue tunnel, is shown in Fig. 48. The concrete footing courses of the side walls were first laid, these projecting inward about 18 inches from the face of the wall. On these projections track rails were laid on each side of the tunnel for carrying traveling platforms. There were three of these platforms; the forward one (Fig. 49) was made for

building the side walls, a center one carried a derrick, and the third (Fig. 50) was employed in building the arch.

Fig. 49 shows the construction of the traveler used in building the side walls. This platform was mounted on six wheels in all, and on each side there was mounted an adjustable lagging, curved to fit the profile of the wall. In operation this platform was rolled to place, and the lagging adjusted to position and held by wedges. Skips of concrete were then hoisted onto the platform and the concrete was shoveled into the space between the lagging and the rock and rammed until it reached the top of the lagging. When the concrete had set, the wedges were loosened and the platform was moved ahead and adjusted for building a new section.

The derrick platform was $22\frac{1}{2}$ feet wide between center of

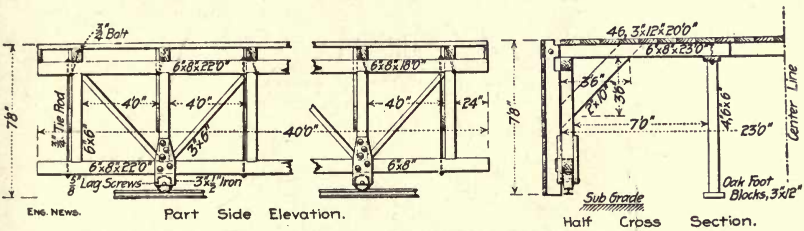


FIG. 49.—New York Subway: Platform for Building Side-walls.

track wheels and was 18 feet long over all. Transversely it was divided into three bays, the center bay being unfloored so that concrete skips could be hoisted through it from the cars running on a track beneath the platform. A derrick was mounted at the center of one of the floored bays, and this derrick served both the side wall and the arch platforms.

The roof-arch platform is shown in Fig. 50. It was practically the same as the side wall platform, with the addition of roof-arch centers at each bent. The top of the completed side walls reached the point *B*, while the roof-lagging commenced at *A*. The space *A B* was bridged by using special sector-like forms. The concrete was shoveled into the arch, commencing at the spring on both sides, until the arch was too high for convenient handling from the platform. When the throw became

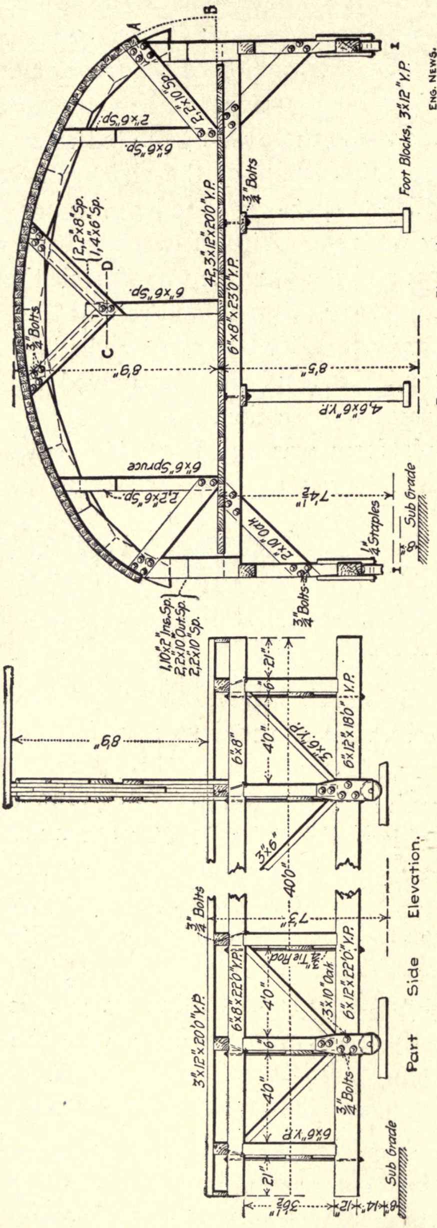


Fig. 50.—New York Subway: Traveling Form for Building Concrete Arch.

excessive, the concrete was shoveled from the skip onto the small platform *C D,* and then into the arch.

When the two sides approached within 5 feet of each other

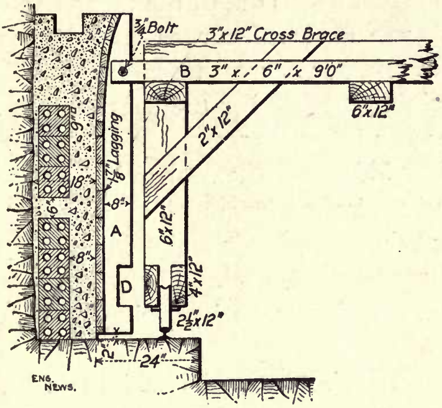


FIG. 51.—New York Subway: Side-wall Mold.

at the crown, this key was built in by working from the rear forward.

In certain sections of the New York Subway the side wall

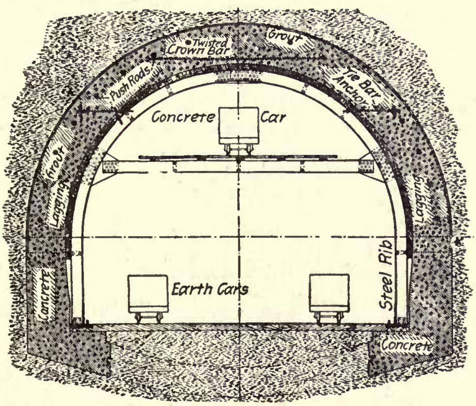


FIG. 52.—Steel Arch-center: East Boston Tunnel.

mold was made as shown in Fig. 51. This was mounted on the traveling platform already described in Fig. 50.

Steel-rib Center.—In building the East Boston tunnel, an extension of the Boston Subway, a steel rib was employed to sup-

port the lagging used in building the concrete-steel lining. The clear dimensions of this tunnel were 20.5 feet high by 23.3 feet wide, and the steel-rib support was devised to facilitate the rapid transport of all debris out of the tunnel, and concrete into it. The ribs were made of curved steel beams riveted and braced together, and on the cross tie-beams provided a platform was laid containing a track for the concrete cars. The muck cars ran on the two lower tracks.

Steel Traveling Shields.—The Moncreiffe Tunnel,* England, has been recently enlarged from a single to a double track section, the traffic being meanwhile maintained on the single-track line in the center of the tunnel. The work of reconstruction was done by means of four steel traveling shields, designed as follows:

Each shield was 32 feet long, divided into 9 ribs, and each rib was made of a curved channel (9 x 4 inches) shaped to fit the inner section of the new masonry. Inside this channel member were two vertical posts and a horizontal top beam arranged to leave a clear rectangular space for the passage of trains, 13 feet 8 inches wide and 13 feet 6 inches high. The external width of the shield itself was 22 feet, and the height was 16 feet 8 inches. The vertical posts and the outer channels were latticed together, and two inclined members, reaching from the crown point to the springing point on each side, tied the posts, horizontal beam and outer channels together. The shield was tied together longitudinally by beams and cross braces between the ribs.

The feet of the outer channel and the inner posts were carried on four sets of longitudinal steel beams; under these beams were four sets of cast-iron wheels, and between these beams, on each side, was a clear space of 2 feet 3 inches to permit the passage of narrow iron cars running on a separate track of 13-inch gage and used for bringing in supplies and transporting waste material.

In operating this shield the side rock was excavated and the

*Proceedings of The Institution of Civil Engineers; Vol. CLXI, September, 1905.

side walls were built in advance. The shield was then used as a staging for the workmen for dealing with the arch portion, and as a protection to the traffic on the railway. The unlined portions of the old tunnel were reconstructed in lengths of 12 feet, so that the 32-foot shield projected 5 feet under the previously built new arch and 15 feet under the old arch, thus giving an ample margin of protection. Where crown-bars had to be used to prevent the fall of large pieces of loose rock in the roof, these bars were supported by posts resting upon the steel ribs. When the necessary rock excavation had been completed, ordinary

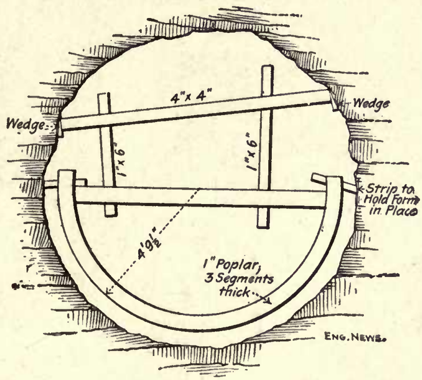


Fig. 53.—Method of Setting Form for Concrete Invert.

wooden tunnel centers were used for building the new arch, located in the rear of the steel shield.

Concrete Form for Small Tunnel.—The form illustrated in Fig. 53 was used in laying the concrete invert foundation in the Cincinnati Water Works tunnel. The concrete was laid in 16-foot sections, the forms being set 4 feet apart. The interest in this form chiefly lies in the simple manner devised for holding the form in place.

After the brick invert had been laid on this concrete foundation, the brick arch was built on lagging supported on ribs made of two 3 x 4 x $\frac{3}{8}$-inch angles, bent to form and riveted.

CHAPTER VII

SUB-AQUEOUS TUNNELS AND TUNNEL SHIELDS

Introduction—Form of shield and method of driving at East Boston Subway—The East River gas tunnel—Massachusetts pipe-line tunnel—Blackwell tunnel—St. Clair tunnel—Berlin-Spree tunnel—Harlem River tunnel—Pennsylvania R. R. Hudson River tunnel—Screw-jack shield—Shankland shield.

Tunnels of the type here discussed are usually located under a waterway separating parts of one city, or are found on lines of railway where it is deemed more economical and as better meeting the demands of general traffic, to tunnel under the waterway rather than to bridge it. Where rock is found in tunnels of this description, the line of the tunnel is necessarily so near to the surface of the rock that the work is liable to be seriously interfered with by the occurrence of vertical seams filled with decomposed rock and communicating with the water above. And when the material penetrated is other than rock it is an alluvial deposit also more or less water-bearing.

Conditions of traffic—as well as those of construction—require that these sub-aqueous tunnels be located as near to the water-level as the depth of water in the channel and the nature of the material penetrated will permit; otherwise, the gradients or the length of the tunnel may be excessive for the purposes of construction or operation. Owing to these facts tunnels of this nature are usually difficult to build, costly and more or less dangerous to the working force; and various methods have been devised to minimize the dangers to be encountered and to facilitate the work of driving the tunnel. Chief among these is the use of shields and compressed air, employed together or separately. As shields for supporting the face and roof and guarding against the inrush of material or water, are an essential

feature of sub-aqueous tunneling, this chapter deals largely with this engineering device.

Historically considered, the first sub-aqueous tunnel of any importance, and through soft ground, is that under the River Thames, in London. This tunnel was first proposed in 1798, by Ralph Dodd; and in 1807 work was actually commenced upon it by the Cornish engineer, Trevithick, and a small drift was run under the river for a length of 1,046 feet. But as some doubt had been raised as to the accuracy of this line in direction, Trevithick made an opening in the top to test his position, with the result that he let in the water and nearly drowned himself and his party. The project was taken up in 1824 by Mark Isambard Brunel; but again the water broke in and the tunnel was abandoned for a time.

Brunel then devised a sectional shield for protecting the advance working, the first shield of record, and by its use the tunnel was opened to foot passengers in 1843. This original Brunel shield was made up of a strong iron framework built in horizontal sections of a comparatively small depth that could be advanced separately, and cut vertically into three compartments. The sections were advanced by powerful screw-jacks, and the vertical face was protected by horizontal poling-boards that could be handled separately and pushed forward as the ground was excavated. The brickwork, covering two arches of 14-foot span each, was built behind the shield as this advanced. This Thames tunnel was 1,300 feet long, and in its extreme dimensions it was 35 feet wide and 20 feet high.

Hydraulic rams for pushing forward the shields, and a permanent iron lining in which to lay the masonry, were probably first used in 1868-69 in building an 8-foot tunnel under the Thames; the next prominent use of the hydraulic jack was in the 10-foot tunnel of the City and South London Subway, completed in 1890; and jacks of this type were used on a large scale on the Blackwell tunnel of 1890, and the 20-foot St. Clair tunnel of 1892, and in the Paris sewer tunnels of 1896. Since these dates the use of shields has been extended in many countries, and the development of this process of excavation is best

noted by the description of typical actual modern work of this class.

Blackwell Tunnel.—This tunnel under the Thames, completed in 1895, is 27 feet diameter, making it the largest sub-aqueous tunnel built to that date. The material penetrated was chiefly water-bearing sand, loose gravel and some good clay. At one point in its length only 5 feet of so-called "ballast," or small water-worn stone, covered the roof of the tunnel; and at this point clay was dumped to a depth of 10 feet and 150 feet in width, to protect the workmen from an inrush of water. The river portion of the Blackwell tunnel is 1,212 feet long.

The shield here used was chiefly remarkable for its unusual size and its somewhat complicated design. As shown in Fig. 54, this shield was circular in form, 28 feet 8 inches in outside diameter and it was 19 feet 6 inches long over all; it weighed 230 tons. The outside shell was made of four $\frac{5}{8}$-inch steel plates, and the interior was divided and the shell stiffened by two vertical diaphragms, $25\frac{1}{2}$ inches apart. The space between these diaphragms was to be used as an air-lock should conditions demand a greater air-pressure at the working face than at the rear of the shield; but there was no occasion to employ this differential pressure. The material excavated at the face was passed through these diaphragms by chutes provided with doors at each end and acting as air-locks.

Horizontally, the forward part of the shield was divided by three platforms, forming four working stages for the men. The three longitudinal and vertical partitions cut the face into twelve compartments and also acted as stiffeners. About $6\frac{1}{2}$ feet back from the cutting edge, in each one of these twelve compartments, a vertical cross screen was introduced, about 30 inches in depth from the top; these screens being intended to form a place of refuge for the men in case of an inrush of water, as the air in these closed places would keep them from filling with water.

The shield was pushed forward by 28 100-ton hydraulic jacks abutting against the cast-iron tunnel lining inside the rear hood. This tunnel lining was very heavy, each segment weigh-

Total Length 6000'+ 27' Diam
& Cost 700 p. ft.

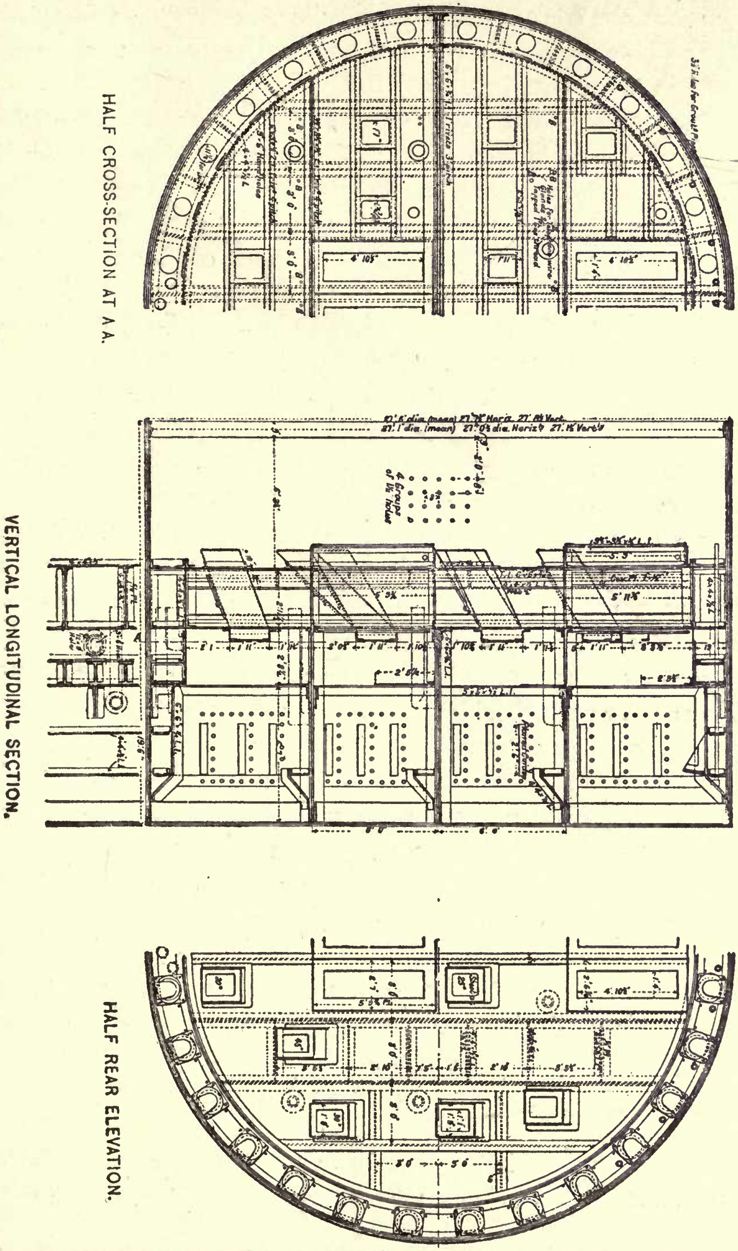


FIG. 54.—Hydraulic Shield and Lock: Blackwell Tunnel Under the Thames.

ing about one ton—and two hydraulic "erectors" were used to lift and hold up a segment until it could be bolted to the segments in place.

This shield proved unwieldy, and after about 125 feet of the tunnel had been driven with it the cutting edge encountered a boulder in the sand and was bent upward at the bottom. The shield was pushed forward about 192 feet further, but it then became so damaged as to be useless. As it could not be withdrawn, it was forced forward to the next shaft by driving a timber advance bottom-heading, and laying down in this a concrete bed upon which the shield could slide, the injured part being thus relieved of strain.

St. Clair Tunnel.—This tunnel passes under the river of the same name connecting Lakes Huron and Erie. The tunnel is 2,465 feet long between centers of shore shafts, and is 21 feet 6 inches in outside diameter. It is located in a bed of blue clay, with the bottom of the tunnel about 60 feet below water level, and was built inside a circular cast-iron lining by means of a shield designed by Joseph Hobson, the Chief Engineer.*

The chief interest lies in the size and form of the shield used. As here shown, this shield consisted of a cylindrical shell, 21 feet 6 inches in external diameter and 15 feet 3 inches long over all. The shell was made of 1-inch steel plates butt-jointed with plain joints; and the segments forming the shield were united by double angles on the interior face, riveted to the shell and together. The shield bulkhead was placed four feet back of the rear end. It was made of ½-inch plate, with seven horizontal and three vertical stiffening members. In the lower part of this opening were two openings, 6 feet high by 4½ feet wide, passing the material excavated; these openings were closed by sliding doors suspended by chains. But, as a matter of fact, these doors were never closed throughout the execution of the work.

To push the shield forward twenty-four hydraulic jacks were installed in the outer ring. Each jack had two cylinders:

*For a detailed history of this tunnel see *Engineering News*, Oct. 4, Nov. 8 and Dec. 20, 1890.

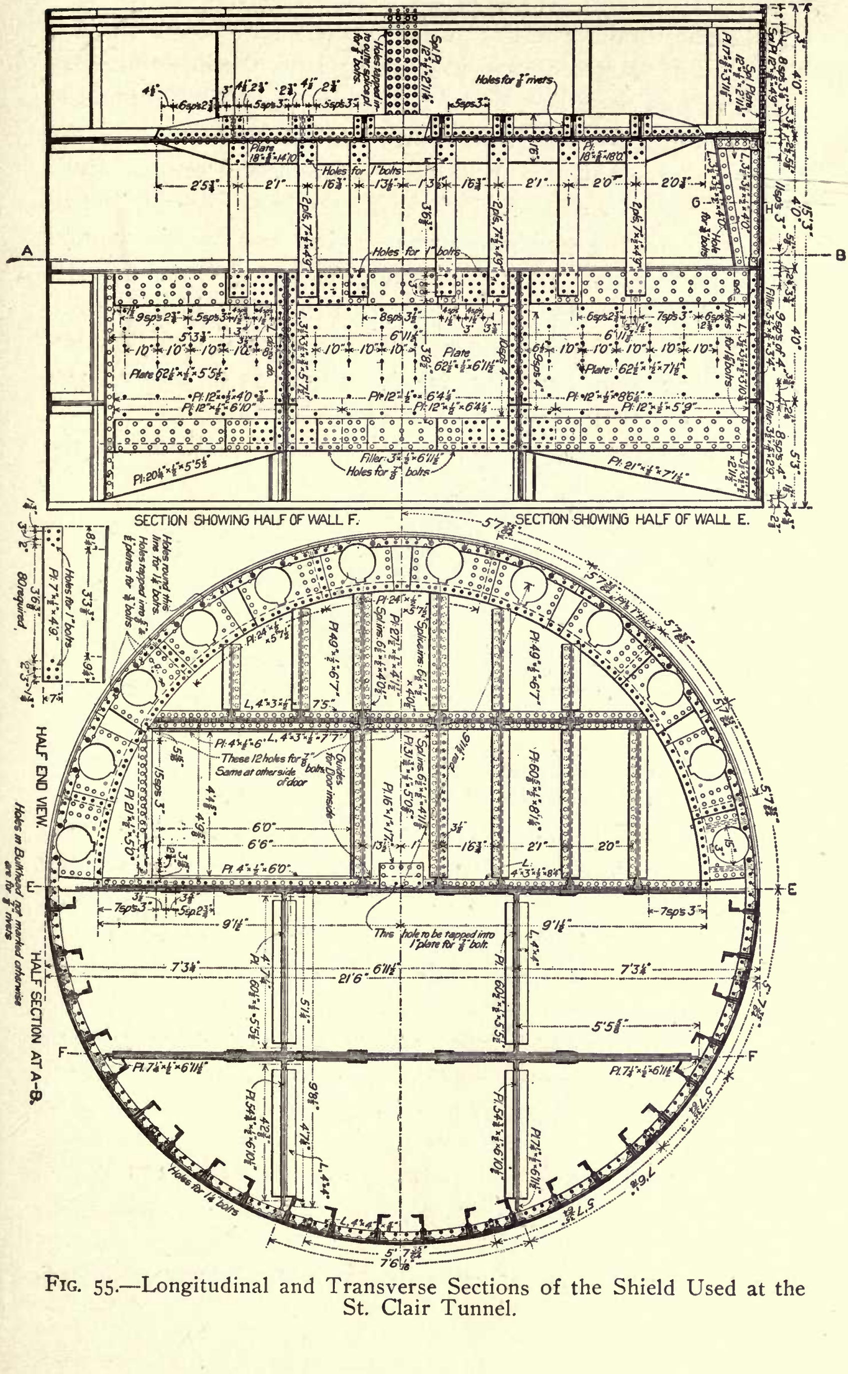


Fig. 55.—Longitudinal and Transverse Sections of the Shield Used at the St. Clair Tunnel.

one 8 inches in diameter, to push the shield forward; the other, $2\frac{3}{8}$ inches in diameter, used in drawing back the large plunger to make room for a new set of lining rings. With a hydraulic pressure of 2,000 pounds per square inch, the first set of jacks exerted a force of 99,000 pounds, and the second 7,250 pounds. The arrangement of these jacks is shown in the illustration.

In front of the bulkhead three vertical and two horizontal partitions were built, to stiffen the shell and to serve as platforms for the workmen. Both sets of partitions stopped within 4 feet of the bulkhead, or diaphragm, thus leaving abundant room to throw the clay down before the bottom openings; these partitions were sloped back from the face, as shown.

Mr. Hobson made some calculations on the friction of the

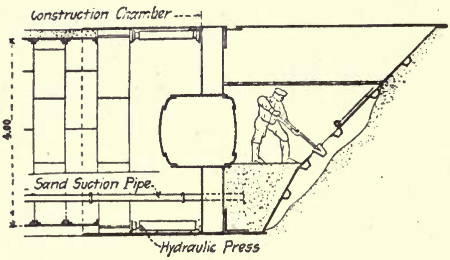


FIG. 56.—Shield Used at Spree Tunnel, Berlin.

cylinder in moving through fairly homogeneous clay. The pressure used to drive the cylinder forward varied from 450 to 2,000 tons, and the area of skin of the cylinder was 1,030 square feet in contact with the clay. The theoretical friction was, therefore, about 875 to 3,880 pounds per square foot, or 6 to 27 pounds per square inch.

Berlin Tunnel Under the Spree.—This tunnel is 1,490 feet long under the River Spree, and is 13.12 feet in outside diameter, lined with cast-steel flanged rings, coated inside and out with cement mortar. The tunnel bottom lies about 40 feet below the mean water level, with a least thickness of 10 feet of soil above the shell. The material penetrated was mud and sand, heavily charged with water. The steel cylinder rings are 2.13 and 1.64 feet wide, and each ring is made of nine segments

fitted with inside flanges. Between these rings, during erection, flat steel circles were bolted, extending outside the shell and increasing the rigidity of the tube.

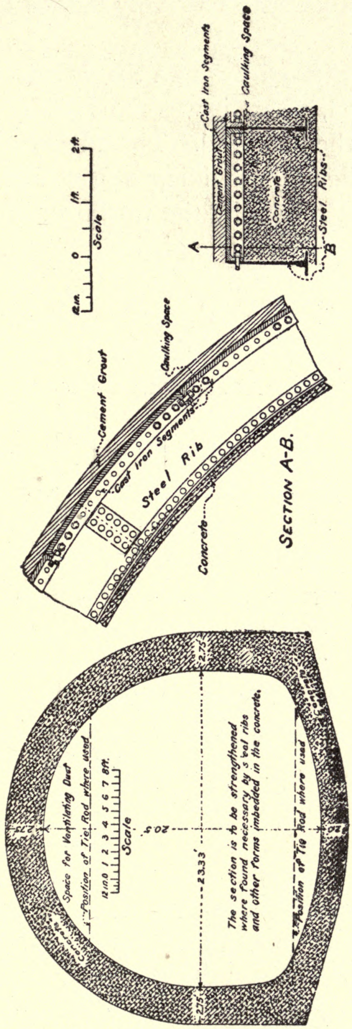


FIG. 57.—Boston Subway: East Boston Extension, Showing Standard Concrete Lining and Steel Ribs Imbedded in Concrete.

The actual excavation was conducted under compressed air and with a shield. As shown in Fig. 56, this shield had a

double bulkhead, with an air-lock passing through both; and in the rear of this transverse partition were the hydraulic jacks. In front of the bulkhead was a hood, cut away at an angle of 45°, with this oblique face closed by hinged doors, which may be opened at will.

The material removed through the doors was thrown to the bottom of the hood, where it was removed by a sand-pump extending through the bulkhead. The advance hood was permanently closed at the top, providing a space filled with air, which could be used as a refuge by the workmen in case of a sudden rush of sand and water. The air-lock, placed in the bulkhead, is intended for similar use.

The actual construction chamber lay between this shield and a temporary transverse wall, built at some distance to the rear and fitted with two air-locks, one for men and the other for materials.

The steel rings were mounted under the rear of the shield, with some space left between the lining and the rear hood of the shield. In this annular space cement was rammed in place; this cement acting as a protection to the metal shell and also as a seal against sand and water from without. In pushing forward the shield the sixteen hydraulic jacks acted against the steel lining ring. This tunnel was completed in 1899.

East Boston Extension: Boston Subway.—This tunnel for about 2,250 feet of its length passes under an arm of Boston Harbor, with 16 to 18 feet of earth over the outside of the tunnel roof at the deepest part of the harbor, where there is 35½ feet of water at mean low tide. The material being generally clay, but somewhat treacherous, the construction called for a roof-shield. A horse-shoe section was adopted for the tunnel, (Fig. 57), with a clear width of 23 feet 4 inches, and a clear height of 20 feet 6 inches. Owing mainly to the high cost of iron, a concrete shell was built about this tunnel, 2 feet 9 inches thick at crown and sides, and 2 feet thick in the invert. In water-bearing material this shell was tightened and reinforced by a cast-iron shell of flanged and bolted segments, having steel plate ribs imbedded in the concrete, with cement grout forced

between the cast-iron shell and the grout. This construction is also shown in Fig. 57.

The roof-shield actually used on this extension was semi-

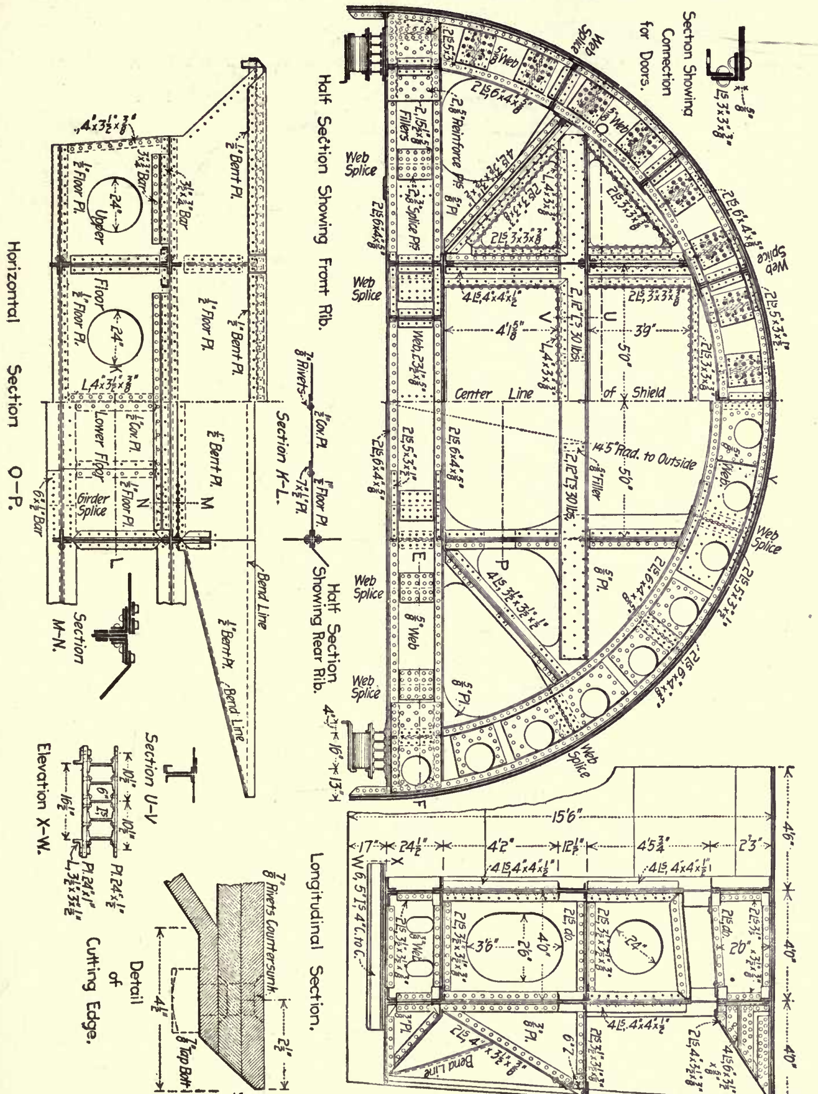


FIG. 58.—Roof-shield, Boston Subway, East Boston Extension; Front and Rear Rib and Longitudinal Section.

circular, tied together at the base by a transverse girder and stiffened by vertical and diagonal riveted plate and angles. It is shown in Figs. 58 and 59.

East River Gas Tunnel.—This tunnel is used for piping gas under the East River, and serves as a typical illustration of tunneling in a treacherous, water-bearing material; it was built in 1894 by the East River Gas Company, under Mr. C. M. Jacobs as Chief Engineer.

From center to center of shore shafts the tunnel is 2,516 feet

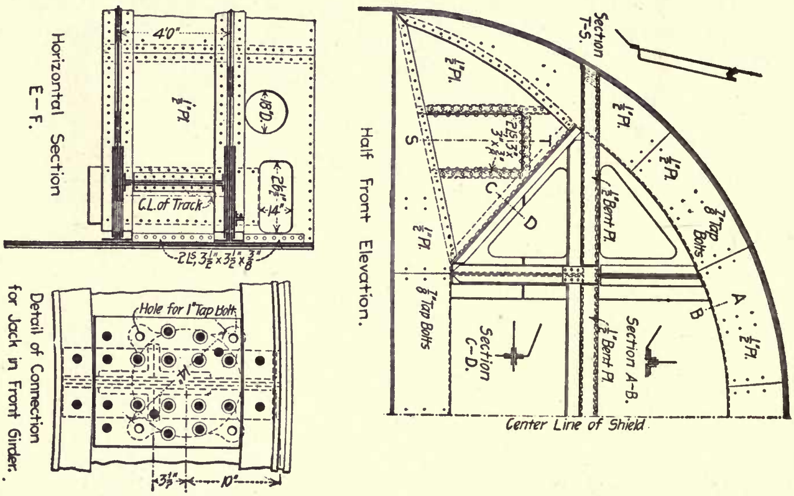


FIG. 59.—Roof-shield: Boston Subway; Half Front Elevation and Jack-connection.

long; the center of the tunnel is 107 and 119 feet below mean low tide, giving a drainage toward the Long Island side. In the solid rock the section is 10 feet wide by 8½ feet high at the crown, and in soft ground a cast-iron shell (Fig. 60) is used, 10 feet 2 inches in diameter clear of flanges. The material penetrated was hard gneiss rock for the lower part of the tunnel; but for something over 200 feet the tunnel passed through almost vertical layers of decomposed felspar, a greenish, marl-like formation that ran like paint when wet, and loose rock. All of this material was water-bearing, the vertical seams communicating with the river above.

The hard rock portion was tunneled in the usual manner without difficulty; but for the soft ground part a shield and iron lining were required, operated along with compressed air.

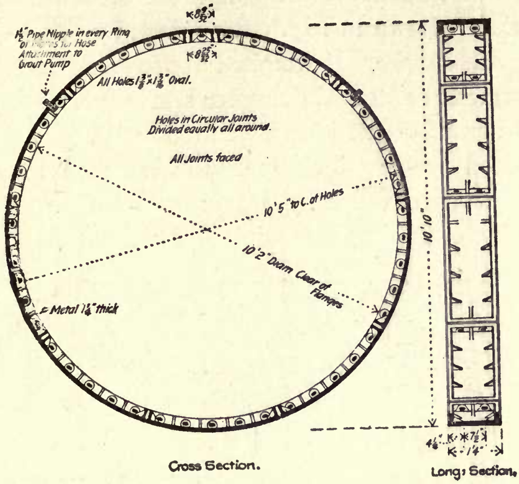


FIG. 60.—East River Gas Tunnel: Cast-iron Lining.

The cast-iron lining was 10 feet 10 inches in outside diameter and was made in rings 16 inches wide, and in nine flanged seg-

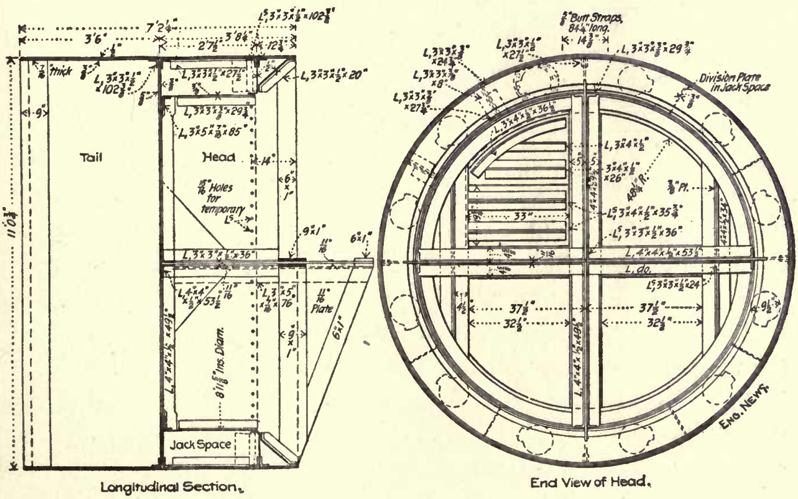


FIG. 61.—Shield: East River Gas Tunnel.

ments with a key-piece 8 9-32 inches long. Every segment was drilled for a 1½-inch pipe nipple for hose attachment to grout-pump. This iron lining was chiefly adopted because it was found that water was forced through the brickwork first tried.

The shield is shown in Fig. 61, planned by Mr. W. I. Aims, the engineer in charge. It weighed about twelve tons, and was 10 feet ¾ inches in external diameter and 7 feet 2¼ inches long: its general arrangement is shown in the cut. In the annular space indicated twelve 5-inch hydraulic jacks were located, each designed to work under a hydraulic pressure of 5,000 pounds per square inch, making it possible to exert a force of 600 tons

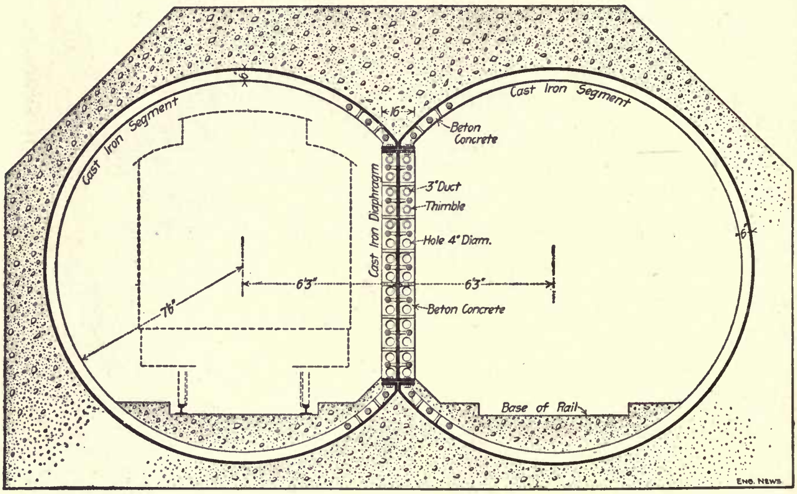


Fig. 62.—Twin-tube Tunnel Under Harlem River.

in pushing the shield forward. The shield and heading were lighted by incandescent lamps, and were connected with the office above ground by a telephone.

As the axis of the tunnel was 120 feet below mean low tide, the air pressure required ran from 48 to 52 pounds per square inch, a record surpassing that of any other known work conducted by the plenum-pneumatic process. Notwithstanding careful physical examination of the workmen, and the use of every precaution, in leaving or entering the air-lock, there were

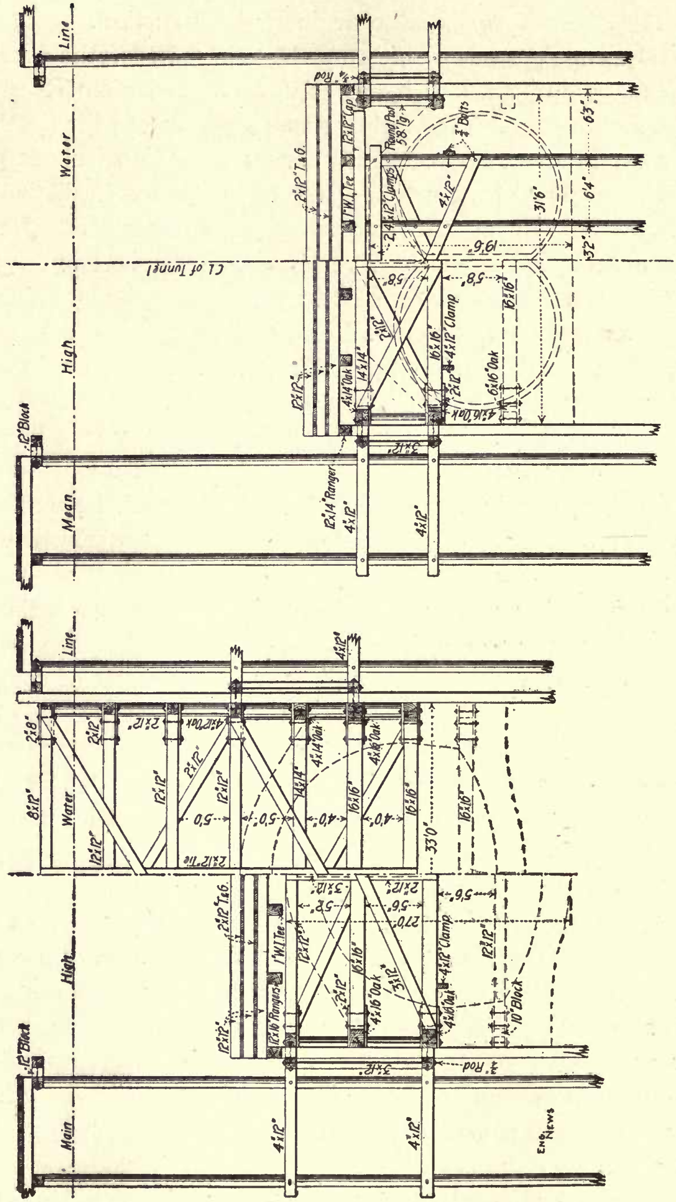
four fatal cases, due to carelessness in entering or leaving the lock. The air-lock was of the ordinary construction.

Harlem River Tunnel.—This tunnel forms part of the New York Subway system, and it passes under the Harlem River, with the rail-base 44.66 feet below mean high water; the depth of the river is about 26 feet, with a range of tide of about 5 feet. The material penetrated by the tunnel is mud, silt and sand, the latter flowing with remarkable ease when wet. Between the bulkhead lines the river is 400 feet wide; but for 610 feet the tunnel is made of two cast-iron cylinders, imbedded in concrete, as shown in Fig. 62.

To build this section of tunnel Mr. D. D. McBean, of the sub-contracting firm, devised the following plan: He proposed to enclose the space to be occupied by the tunnel by two lines of specially constructed 12-inch tight sheet-piling; upon these lines of piling, carefully cut off at the proper level, he would lay a timber roof made of three layers of 12-inch timbers, with courses of 2-inch plank running at right angles between the heavy courses, all well caulked, and making a roof 40 inches thick. Under the protection of the box so made, he proposed to excavate the material, either with or without the use of compressed air.

Before driving the sheeting the river had been dredged to such an extent as to leave an average depth of 7 or 8 feet of material to be removed in the chamber to be formed. Then four longitudinal rows of piles were driven under the proposed tunnel, 6 feet 4 inches apart, c. to c. transversely, and 8 feet apart longitudinally. These piles were cut off and capped as shown in Fig. 64, their office being to support the heavy timber roof; to support the interior bracing system; and to be eventually cut off at sub-grade and further support the finished tunnel. A substantial pile service platform, 20 feet wide, placed parallel to the tunnel line and on both sides of it, aided materially in the accurate alignment of the bearing piles and the placing of the bracing.

To accurately align the two rows of sheet piling, a timber frame was constructed to fit closely between the two lines of



FIGS. 63-64.—Harlem River Tunnel: Transverse Sections Showing Working Platforms; Interior Piles, Bracing and Guide-frames; Sheet-piling and Roof.

sheet piling to be driven, with the center of this frame exactly over the center line of the tunnel. This frame, shown in part in Fig. 64, was built in lengths of 216 feet, and floated between the service platforms, accurately aligned and sunk. As this frame was now exactly opposite another frame bolted to the pile platform, the space between them formed a true guide on either side for driving the sheet piling.

The sheet piling (Fig. 65) was made of 12 x 12-inch long-leaf yellow pine, in sticks usually 65 feet long. Three of these sticks were bolted together so as to form a single unit 36 x 12 inches; and these were "tongued and grooved" by spiking 3 x 4-inch pieces on each edge, suitably arranged.

To further insure accuracy in the driving of this sheet piling,

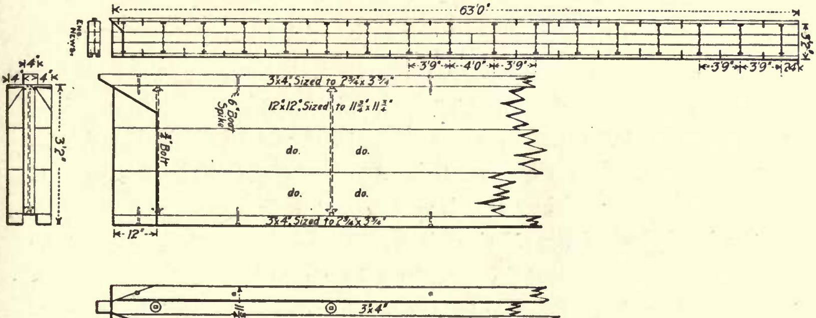


FIG. 65.—Sheet-piling Used at the Harlem River Tunnel.

pilot-piles were employed with great advantage. These were made of steel channels and plates, forming a 12 x 12-inch pile 60 feet long. They were fitted with pipes running down through the pile point so that a water-jet could be used in washing away the material. Three of these piles were very carefully driven on the spot to be occupied by the sheet piling; they were then withdrawn and the timber sheeting at once inserted in the hole and driven to refusal with a 6,000-pound hammer. The advantage of the pilot-pile was that by its use boulders and other obstructions could be detected and removed before the permanent piling was driven. The sheeting, when

driven, was carefully cut off by a circular saw to the exact level required by the plans.

With the sheeting in place, and the roof described thoroughly bolted together and caulked, lengths of this roof, varying from 39 to 130 feet in length, were floated into place. Previous to this six lines of 12 x 14-inch range timbers had been bolted to the bottom of this roof; and when the latter was sunk these timbers rested exactly upon the two rows of sheet piling and the four inner rows of piles. To the outer lines of rangers bolted under the roof system T-irons had been fastened, and the vertical web of these irons cut into the sheet piling under the weight of the roof. This T-iron was intended to assist in making a tight joint between the roof and the lines of the sheeting; but as the silt soon washed in and closed any small crevice, they were unnecessary.

The sunken roof was next overlaid with about 5 feet of earth or mud, dredged from the immediate vicinity, to bring the timber roof to a firm bearing and also to provide weight against the uplifting tendency of compressed air used within the working chamber. Each end of this chamber was closed by a suitable bulkhead, making the length of the chamber 216 feet, or about half the width of the river. The other half of the river was left unobstructed for traffic. In the center of this length a timber air-shaft was built, 7 x 17 feet, fitted with an air-lock of the usual type. Inside were placed a rotary and direct-acting pump for jetting out the soft material excavated. A material shaft, large enough to take in the segments of the iron lining, was placed near the center, and two smaller shafts were located between the center and the two ends.

When the water was driven from the working chamber by the compressed air, the leakage of air from under the edge of the roof was found to be small, considering the length of the sides, and the sheeting was found to be in excellent alignment. The preliminary work had evidently been done with the greatest accuracy and care. The material inside was excavated with little trouble, and the tunnel lined and concreted.

In building the shore sections of the tunnel the roof was

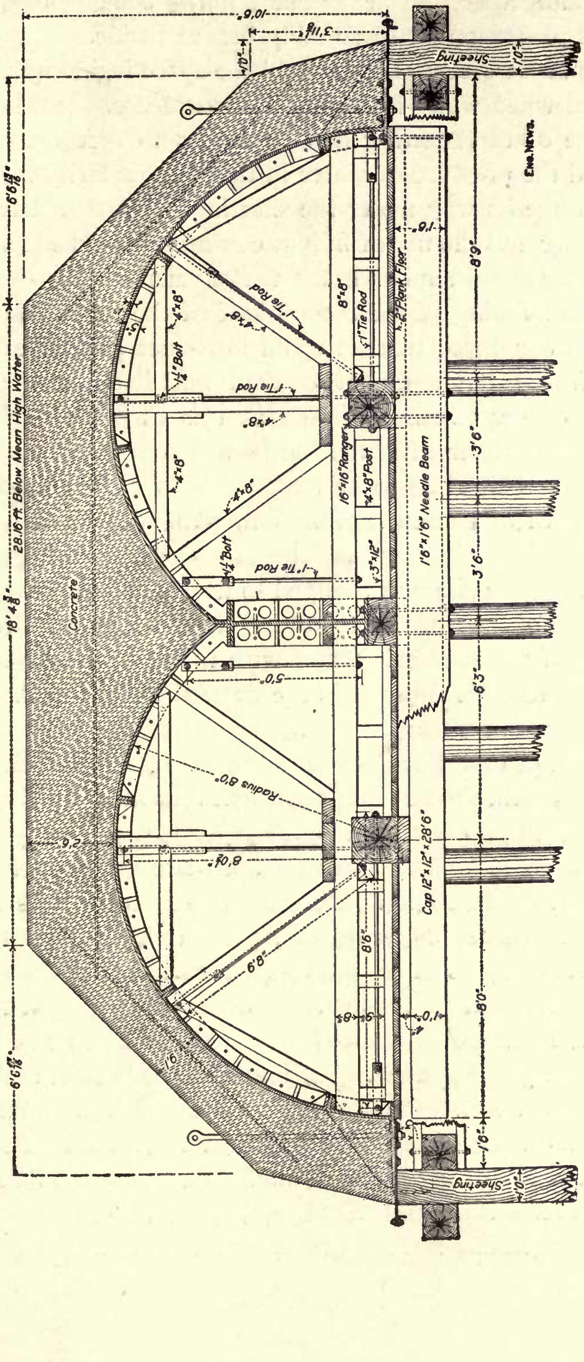


FIG. 66.—Cross-section of Second Method of Building Harlem River Tunnel.

omitted altogether, the heavy sheet piling being considered a sufficient protection when suitably braced inside. The coffer-dam was successfully pumped, and the space inside was nearly completed when water broke into the enclosure. It was found that some of the sheeting had stopped 5 to 8 feet above the rock; and the pressure of water in this soft material was sufficient to force its way under the sheeting. Further driving of the sheeting and the use of filling, cement, etc., outside stopped this and a second similar break that occurred.

For the building of the second half of the tunnel, Mr. McBean was convinced that he could introduce greater economy by substituting the upper half of the tunnel itself for the heavy timber roof described, especially as this timber roof had no function to perform after the tunnel was completed, and a section of it actually had to be removed later to provide the requisite depth of channel. This new plan was carried out as follows:

As before, the site was dredged to nearly sub-grade, and the double line of 12 x 12-inch sheeting was driven for the sides and ends of the submarine box, with inside bearing piles and guide and bracing frames as in the western half. But the sheeting was now cut off at the springing line of the proposed tunnel, instead of on a line considerably above the top of the iron-concrete structure to be built. The box thus made by the sheeting was about 300 feet long.

The roof was built in three sections, two 90 feet long, and one section 84 feet long. To erect this iron-concrete roof a floating box was first constructed, 106 feet long, 35 feet wide, and 12 feet deep. The bottom was made of 12 x 12-inch transverse timbers laid 4 feet apart, and floored with 3 x 12-inch planks; the vertical side sticks were 4 x 6 inches, and to these were spiked 3-inch planks. All joints in the bottom and sides were well caulked. On three 4 x 12-inch longitudinals fastened to the floor of this box was then built a false floor for the upper half of the tunnel. This floor was made of 16 x 16-inch transverse timbers, 8 feet apart, and on these were placed a center longitudinal of 10 x 16-inch timber, and two 16 x 16-

inch timbers laid 6 feet 3 inches each side of the box-center. The space between these longitudinals was floored with 2-inch plank, spiked to the 16 x 16-inch transverse sticks and well caulked. Bolts held this flooring firmly bound together.

Upon this false floor the cast-iron tunnel lining was erected in 6-foot rings; and, as shown in the illustration, rods and braces were introduced as precautions against any possible deformation, and suspension bars were built in for use in sinking this roof. The skewbacks are especially heavy, and have a wide horizontal flange, with an outside vertical guide-flange. It might be mentioned here that this flange was drift-bolted to the top of the sheeting after the roof was sunk. This was done by leaving openings in the concrete covering this flange; and the bolts were then set by a diver and driven by using a guide-pipe and a heavy "follower."

To close the ends of this roof-box, and yet to permit connection with an adjoining section, a vertical diaphragm of $\frac{1}{4}$-inch iron plate was so bolted over the ends as to leave a 6-foot shell-ring outside of the diaphragm. In the center of the top of the projecting ring was a specially provided opening for the use of the diver who was to enter this section and do the connecting of two main tunnel sections. The cover was left off this opening until the diver had finished his work inside. Each 6-foot ring of the iron shell weighed about 41,000 pounds, and it carried 618 cubic feet of concrete. As calculated, the total weight of the iron, concrete floor, etc., was about 50 pounds less per lineal foot than the estimated buoyancy of the empty roof-chamber.

The concreting having been completed according to plan, the roof was now ready to be lowered down upon the sheeting sides. The Bronx shore section, 84 feet long, was the first to be sunk. But before this was done, a short section of the tunnel had been built in an open cut on the shore, provided with horizontal air-locks, and presenting a completed ring for connection, a tight bulkhead having been built over it some little distance inshore of the end before the end of the original cofferdam was removed.

When all was ready for sinking, and suspension tackle had been attached to the eye-bars noted and to heavy beams resting on the surface platforms, water was pumped into the box in which the roof had been built until its floor sunk below the false floor of the tunnel-roof chamber, the buoyancy of the latter having arrested any further sinking of this roof portion. When the clearance was sufficient, one end of the box was removed, and it was pulled out lengthwise from under the roof portion, and was used in building another roof section. Compressed air was meanwhile pumped into the roof to decrease any leakage through the false floor and to maintain the water displacement. To aid in locating the roof on the sheeting, fine wires were set up at each end of the tunnel section and aligned by a transit, and other tag-lines fastened to the tunnel roof were set for longitudinal and transverse adjustment. With these guides the roof was carefully moved longitudinally until the flanges in the projecting 6-foot ring coincided vertically with the ending of the shore section; the roof was then weighted with stone to overcome its buoyancy, and was sunk and connected by a diver, as already described. As showing the care taken, the flanges were bolted together by 1-inch bolts entering 1 1-16-inch holes. This section was now ready for excavation, the separating diaphragm being cut, and after the diver had closed the opening by which he entered the projecting ring.

The other two roof sections were assembled and sunk on the sheeting in a similar manner; but the connection of the last section with the river end of the old western tunnel section required some special provisions. As already noted, the timber roof of this first section was placed so high that the entire tunnel section could be built under it, and the lines of the sheeting were cut off at a correspondingly higher level. Under this roof a section of the tunnel, about 47 feet long, was left unbuilt. The problem was to connect the lower iron-concrete roof section with the high-roof section of the first, or western, half of the tunnel.

The outside transverse bulkhead of the high-roof section

was first cut off to the level of the springing line of the tunnel, or to correspond with the sheeting under the new roof. The river end of the last section of the new roof sunk had been closed by a special diaphragm, which had a flanged base at the springing line, which permitted it to rest upon and be lag-screwed to the transverse sheeting mentioned. But the diaphragm itself, instead of conforming in shape to the line of the twin-tunnel section, as before, was now a rectangular plate

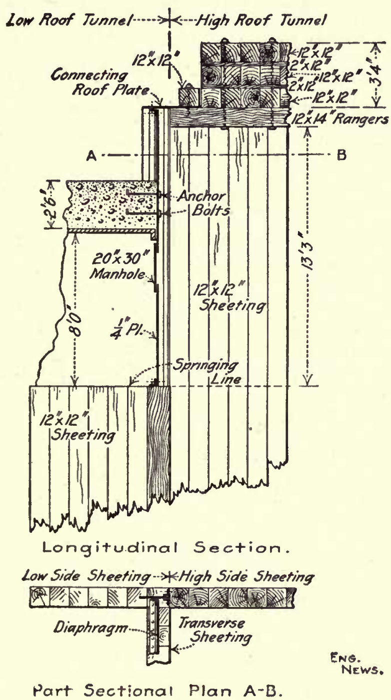


FIG. 67.—Manner of Connecting Old and New Work.

extending to the full width of the transverse sheeting, or 32 feet 2 inches, and it was 8 feet 4 inches high. To the top of this plate was connected by plates and angles another plate of the same width and almost 5 feet high. In the lower plate was a manhole, 20 x 30 inches, and angle irons were riveted to

both sides and the top of the diaphragm plates, to receive the side plates to be put on after the section was sunk.

After the last section had been sunk into place with the diaphragm attached, the latter was first connected by a diver to the line of transverse sheeting by lag screws. Then, to close a space of about 14 inches between the line of the diaphragm and the sheeting of the high-roof section, two side plates and a horizontal roof plate were lowered into position, fitted by a diver against the sides and over the top of the roof-rangers and the bolt-holes marked. These plates were then taken up, drilled to correspond with the holes in the diaphragm flanges, and finally bolted to the timber sides and roof by divers. In this manner a water-tight connection was made between the two sections of the tunnel built on different plans, and with this connection complete the water was expelled by compressed air from the old completed tunnel, and the connecting link of the tunnel was built as in the original plan. In the diaphragm as erected, holes had been drilled for the bolts that were finally to connect the flanges of the abutting tunnel shells, and other holes carried anchor-bolts for connecting this diaphragm with the concrete backing.

Penna. R. R. Hudson River Tunnel.—This novel tunnel, for which the contract is let at this date, is intended to connect Manhattan Island, or New York City, with the Pennsylvania Railway System. The Hudson River section of the tunnel is 5,502 feet long; though with its land terminal connections it will be eventually 5.7 miles long. Under the river the tunnel will be laid in two parallel concrete-lined tubes, each supported on a row of 27-inch screw-piles spaced 15 feet apart. The construction shown in Fig. 68 is made necessary by the unstable character of the fine silt forming the larger part of the bed of the Hudson River at New York.

The cast-iron lining, 23 feet in diameter, is of the usual type, except that a special segment is inserted at the point where the screw-pile occurs. Each lining-ring is 30 inches long and is made in twelve segments, one of the latter being a key-segment 12¼ inches long. These segments have flanges 11 inches deep

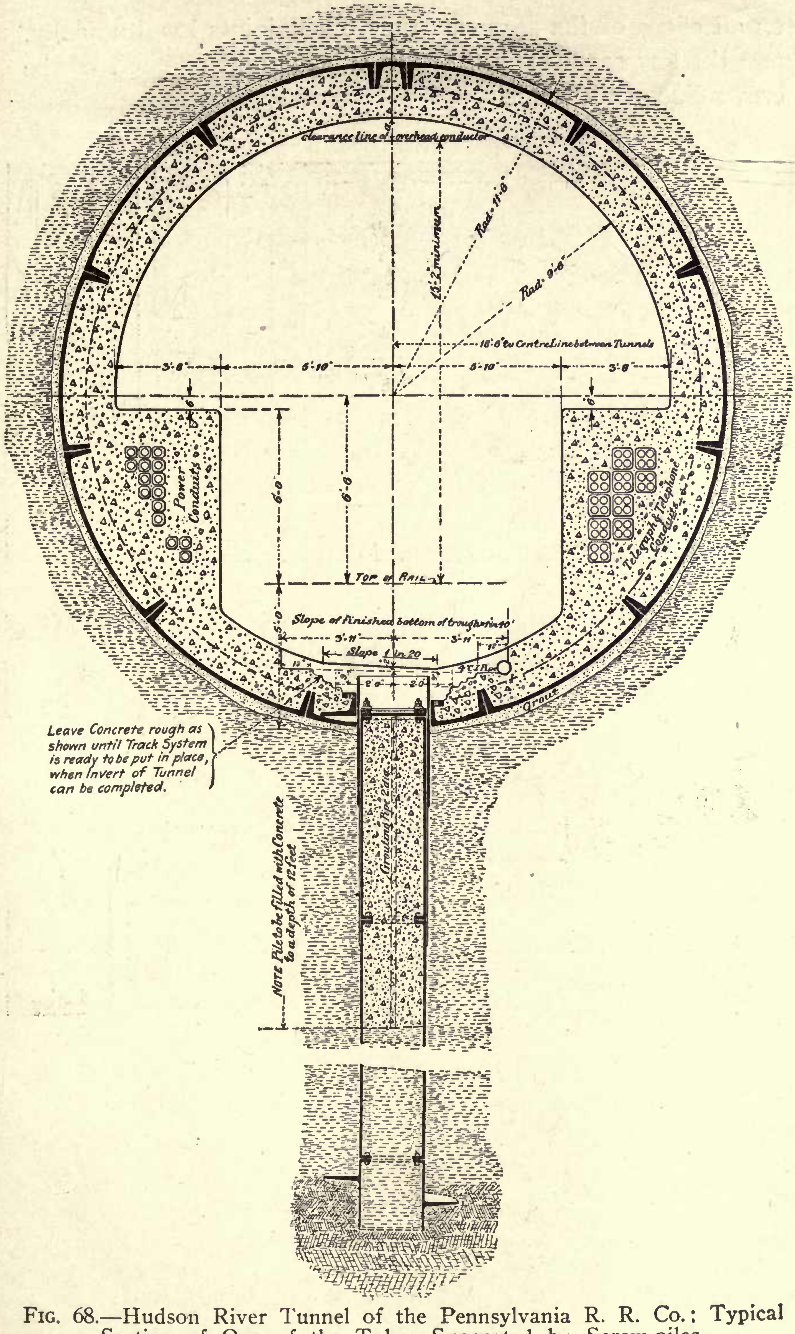


FIG. 68.—Hudson River Tunnel of the Pennsylvania R. R. Co.: Typical Section of One of the Tubes Supported by Screw-piles.

on all edges of the segment; they break joints longitudinally, and the key segment is thus alternately right and left of the crown-line of the tunnel.

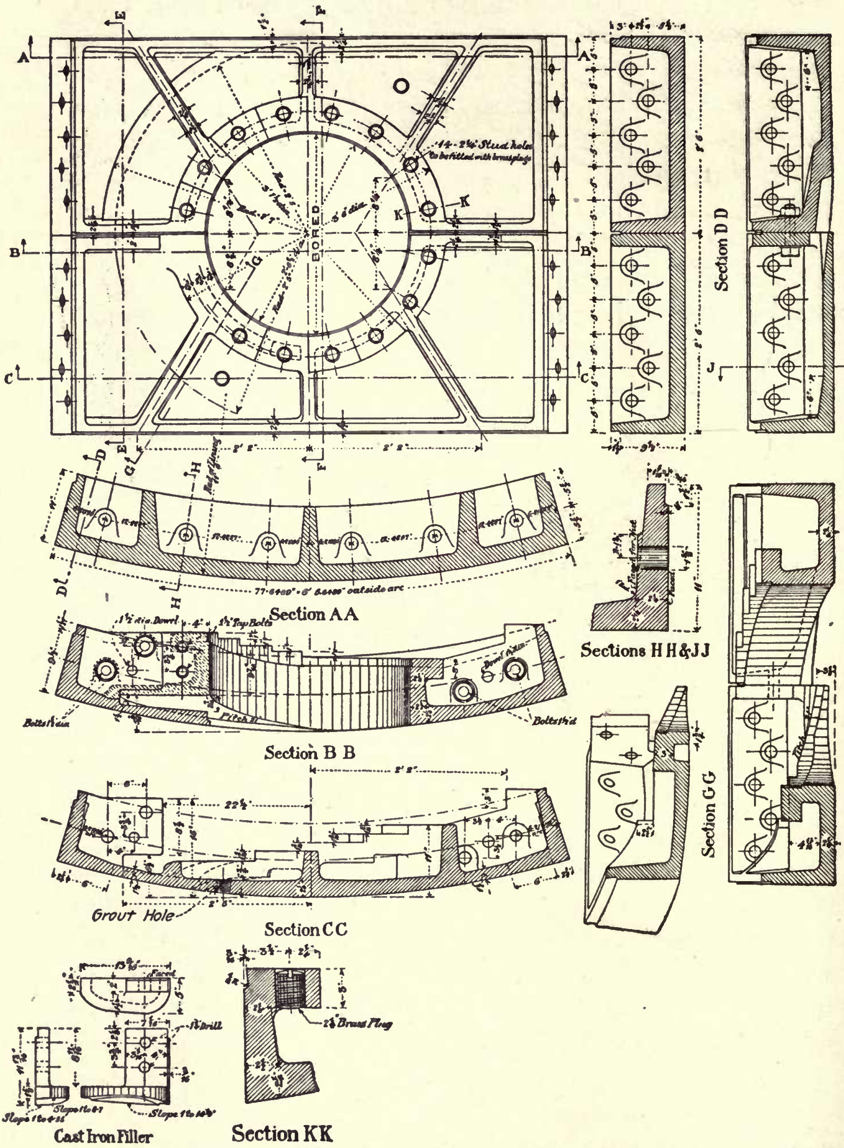


FIG. 69.—Details of Bore-segments of Tube Lining.

The segments through which the screw-pile passes are of special construction, and are made of cast steel, and in pairs occupying the width of two rings. Their construction is shown in Fig. 69. The circular opening in the plates is intended for the shaft of the screw-pile; and to permit the passage of the blade of the screw a slot is left in the casting, as shown. A temporary collar and cast-iron plug close the hole in the lining until the pile is put down; and cast-iron fillers similarly close the slot referred to.

The screw-piles are in general of the usual construction. The helix has one turn, with the usual lap, and a pitch of 21 inches. The shaft is 27 inches in outside diameter and is made in 7-foot lengths, connected by inside flanged joints, with four flange bolts and twelve steel dowels fitting into adjoining circular mortices. These dowels take the torsional strains resulting

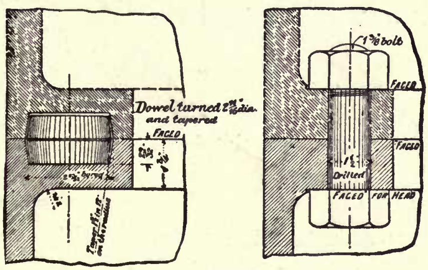


FIG. 70.—Detail of Dowel and Bolt for Screw-pile Shaft.

from the screwing-down of the piles, while the bolts clamp the adjoining sections together, as shown in Fig. 70.

As shown in the general cross-section, the upper part of the pile is enclosed in a sleeve. This is simply a sheet steel cylinder placed as shown, when the pile has been driven down sufficiently to permit it. Its purpose is to provide a sort of cofferdam, in which the final 7-foot length of pile can be disconnected and lifted out, and in which another pile section of the exact required length can be inserted and connected up. The top 12 feet of the pile shaft is filled with concrete.

At or near the intersection of grades and the rock, where some distortion may occur owing to the difference in support-

ing quality in the ground, an expansion-joint construction will be used. This joint (Fig. 71) will consist of a ring within a ring, and these rings will be made of wrought steel instead of cast-iron. The figure shows a section through the rings parallel to the axis of the tunnel.

Quoting here from the specifications, we find that the tunnel portion under the river is to be built by means of a shield and compressed air. Bulkheads and safety screens are to be built across the tube at intervals not exceeding 1,000 feet. These bulkheads shall be constructed of concrete, or brick set in Portland cement; and each shall have two air-locks not less than 6 feet in diameter and 20 feet long—one near the roof, as an emergency lock for the men; and one at the bottom, for passing material, pipes, rails, etc. An air pressure of 55 pounds

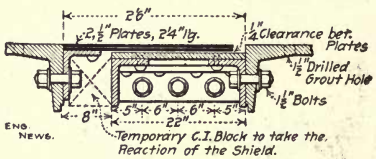


FIG. 71.—Expansion-joint for Tube-tunnel Lining.

per square inch is to be provided for in designing these bulkheads. A safety screen, extending from the roof downward into the tunnel, is to be maintained within 100 feet of each working face.

The contractor is to design his own shield, under certain specifications; and, of course, this cannot be now described.

Screw-jack Shield.—In constructing the water-works at Ripley, N. Y., Mr. E. A. Wilder, C. E., devised a simple shield for use in driving a 700-foot tunnel through clay and a material closely approaching quicksand.

The tunnel was circular, 42 inches in diameter, lined with two rings of brick. As hydraulic jacks would require a special plant for their operation, screw-jacks were employed to push the shield forward.

This shield (Fig. 72) was made of $\frac{3}{8}$-inch plates, connected by 3 x 4-inch angles. As the circular angle was cut away en-

tirely for the pockets for the screws, the engineer advises the use of a 3 x 5 x $\frac{1}{2}$-inch angle for this purpose. The steel jack-screws were $1\frac{1}{2}$ x 16 inches, and brass nuts were used, with a convex bearing seated on a thin concave plate bolted to the circular flange, but not rigidly. This arrangement held the screws always in place, and at the same time permitted a slight movement that prevented binding of the screw. The pockets entirely enclosing the screws answered as brackets, transmitting

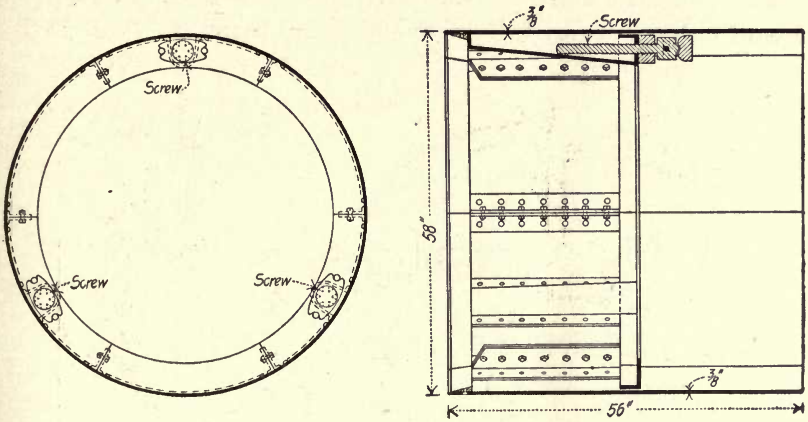


FIG. 72.—Screw-jack Tunnel Shield.

the thrust of the screw to the cutting edge, and prevented sand from coming in contact with the screw.

This shield was built by the Erie City Iron Works, and cost $140 f. o. b. at Erie, Pa.

Shankland Shield.—In constructing the Chicago Intercepting System, in 1902-03, a shield was employed that was practically designed by E. C. Shankland for the contractor.

This shield (Fig. 73) was 24 feet 10 inches outside diameter, and the forward 10 feet of hood was made of 1-inch steel plates. At the middle of this hood is an inside ring made of two 12-inch channels set back to back and 12 inches apart. From the rear of this ring a series of 12-inch horizontal I-beams are spaced 15 inches apart, forming a series of chambers for the hydraulic jacks. The rear ends of these I-beams rest upon another ring of two 12-inch channels. The front part of the

hood is stiffened by eight deep gusset plates, forming extensions of the central, vertical and three horizontal partitions. At the intermediate points there are shallower gusset plates; and all these plates are riveted to horizontal steel angles inside the shell, and to other angles against the 12-inch channel ring. The partitions, dividing the shell into sixteen compartments, are made of $\frac{5}{8}$-inch steel plate, stiffened by double rows of 12-inch steel channels.

The shield was fitted with thirty 65-ton hydraulic jacks, the 5-inch plunger of each jack having an end bearing plate, 8 x 26

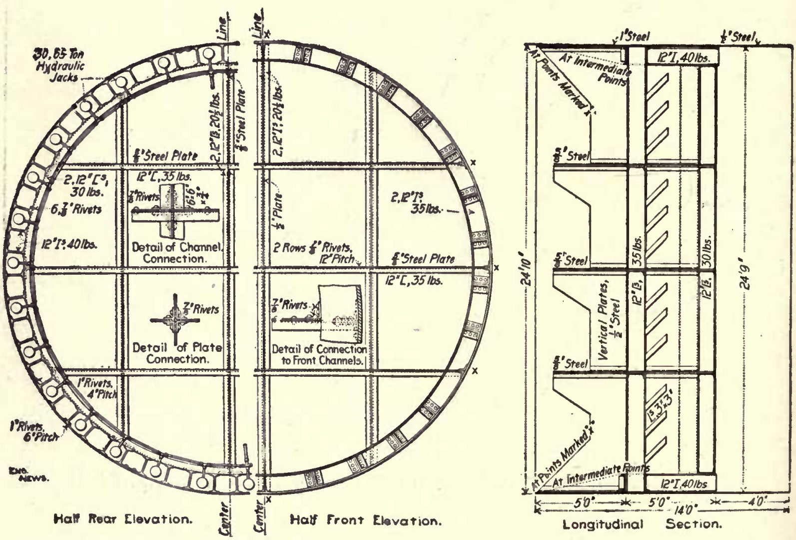


Fig. 73.—Chicago Sewer Tunnel: The Shankland Shield.

inches, butted against the 8-inch circular wooden tunnel lining projecting into the tail of the shield. The brickwork is built inside this lining, the latter being left in place. The average rate of progress with this shield, in 93 days, was 8.74 feet of tunnel in 24 hours.

Timber-lined Subaqueous Tunnel.—In 1901 the Massachusetts Pipe Line Gas Company was compelled to carry its pipe system under the Mystic and Charles rivers, near Boston. Subaqueous tunnel siphons were built for this purpose; and the 42 and 54-

inch cast-iron pipes were protected against corrosion by concreting them inside a wood-lined shaft and tunnel, as here described.

The shafts were sunk by using an ordinary air-lock surmounting a riveted steel caisson. This caisson was sunk in the usual way and extended in 10-foot sections, until material was reached sufficiently compact to prevent the escape of air. The steel caisson was then stopped, and a segmental plank lining was put in. This lagging consisted of circular segments 6 inches wide, sawed from 2-inch plank, and the circle had an outer diameter of 7 feet. There were eight segments to a ring,

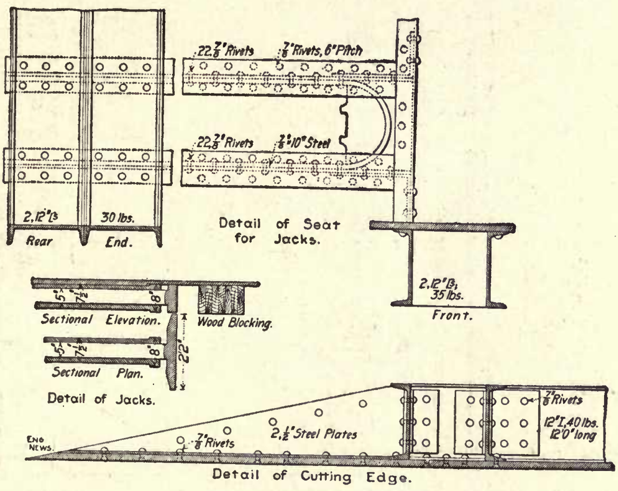


FIG. 74.—Details of Shankland Shield.

and these were spiked together with 7-inch spikes, each ring breaking joint with the one below it. This construction was found to be exceedingly rigid, and it was used in building the tunnel proper. The curved connection between the shaft and the tunnel was made by successively lengthening the diameter of each ring in the direction of the axis of the tunnel, as shown in Fig. 74a.

In driving the tunnels a simple shield of the Greathead type was employed. The excavation was carried two feet ahead of

this shield by placing boards and posts; and the shield was then pushed forward by six hydraulic jacks abutting directly against the wood lining. This operation also tended to close up the joints in the lagging; though, as the timber was thoroughly dry when put in, the swelling of this timber usually

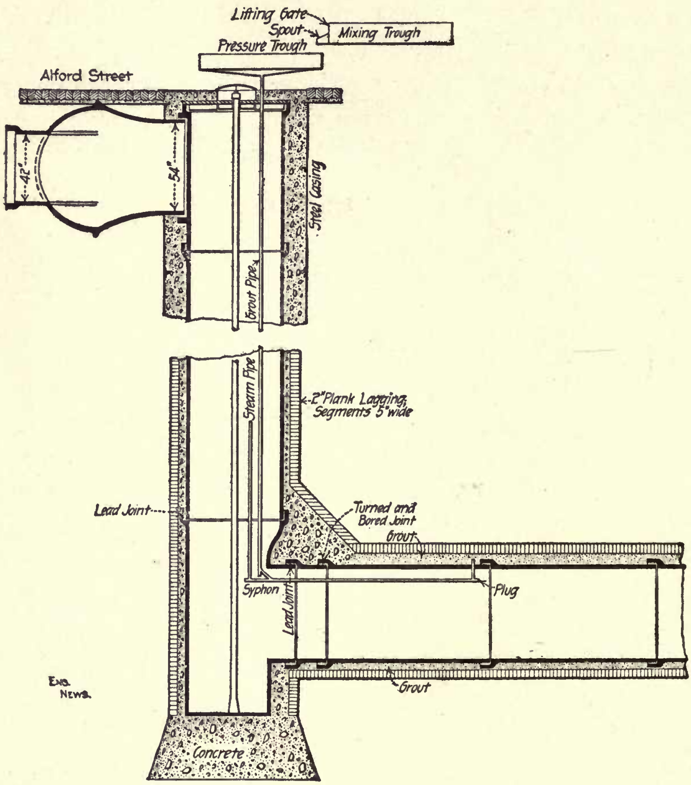


FIG. 74a.—Charlestown Siphon Tunnel: Showing Method of Grouting Cast-iron Pipe.

made very tight work. The lining was given a wash of thin cement after it was in place; and any special leaks were plugged by wooden wedges and caulked, or dry cement was fed into the holes and carried outward by the air pressure.

To preserve the cast-iron pipes from corrosion, and especially to avoid any opportunity for gas-pockets due to leakage,

the space between the pipes and the wooden lining was filled with concrete where space permitted, or with injected grout. In the latter case the grout was run in pipes to holes drilled in the top of each length of cast-iron pipe; and, after various devices had been tried and abandoned, owing to clogging, the pressure due to the height of the mixing trough at the surface was alone used. But the grout pipe leading through the large gas pipe was washed out with clean water after every run.

The cost of this work is given for the several tunnels as follows:* The Malden tunnel, here illustrated, cost $55.64 per

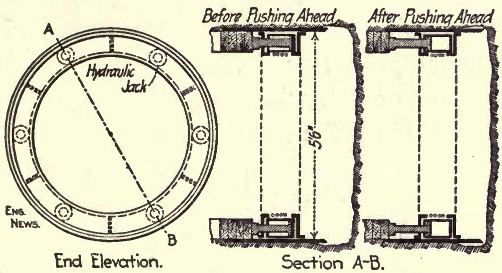


FIG. 74b.—Shield Used by Massachusetts Pipe Line Gas Co.

lineal foot complete; or $35.34 per foot for driving the tunnel, $15.50 per foot for the 54-inch pipe, and $4.80 per foot for laying and grouting. The Charleston tunnel was built without a shield, but under air pressure. The total cost was $101.40 per lineal foot; or, driving $87.45, 42-inch pipe $4.35 per foot, laying and concreting $9.60 per foot. The River Street tunnel was 90 feet below the water level; it was also built without a shield and under great difficulties. It cost $99.65 per lineal foot; or, driving $48.84 per foot, 48-inch pipe $5.36 per foot, laying and concreting $45.45 per foot. The cost of labor on the concrete was about $5 per cubic yard; and the concrete complete in the tunnel cost about $9 per cubic yard.

*Engineering News, Oct. 3, 1901; p. 229.

CHAPTER VIII

SUBWAYS, OR UNDERGROUND RAILWAYS

Location of—Orleans Railway in Paris—Metropolitan Railway of Paris—Boston Subway—East Boston tunnel—Buda-Pest Subway—New York Rapid Transit Subway—Atlantic Avenue Subway in Brooklyn.

Subways, or railways of this type, are comparatively very modern in their application. They have for their object the shortening of time of transit between given points in a great city, and the relief of the surface streets from congestion of traffic.

Subways are constructed both in tunnels and in open cuts; and they may be combined with the elevated roads where the conditions demand such a combination. The extensions of these subways may be carried under rivers separating parts of a great city; but in such cases these extensions are properly classed as subaqueous tunnels, and they are here treated under that head.

Subways are usually located as near to the general street surface as conditions will warrant, for the convenience of the people using them, or to avoid as much as possible the use of long flights of stairs, or elevators, at the stations. At the same time, provision must be made in this location and construction for all existing sewers, water and gas mains, electrical conduits, and other underground pipe or conduit systems. The sewers and water and gas mains are usually carried over the subway; and wire conduits are provided for in the construction of the abutment walls.

Tunneling close to the street surface involves open-cut work, with all its obstruction to street traffic; or the use of some form of roof-shield, when the soil conditions and the depth

of the covering will permit. In solid rock, and at a sufficient depth, the usual method of rock-tunneling is resorted to.

In some of the original London subways, driven through a practically homogeneous clay formation, the tunnels are circular in section, with one tunnel devoted to each of the two tracks. The advantages claimed by the advocates of this twin-tunnel system are: That this arrangement results in a lower initial cost, as the section of the separate tunnels is less than that of a double-track tunnel; and, as these separate tunnels can be arranged side by side, or one over the other, the double line can be kept below a comparatively narrow street. There are also advantages in the ventilation of a single tunnel, by means of the continuous passage of trains in one direction; and the possibility of collision in meeting trains is eliminated.

But there are also objections to this twin-tunnel plan, especially from the point of view of operation; and the cost of maintenance of way is relatively increased, as is that of inspection and signaling. The stations on the twin-tunnel system cost more, as they are necessarily more complicated in the arrangements for entrance and exit. The inability to switch over from one line to another is also objectionable, and special cross-overs must be provided.

Orleans Railway Tunnel in Paris.—This extension of the Orleans railway system into the heart of Paris comes properly under the head of subways in the method of its construction. The execution of the work presented exceptional difficulties: The extrados of the arch was very near the street surface, while the foundation was at times below the water level; the alignment was a succession of curves of large radius; many sewers were cut; and the abutments of bridges, quay walls, old masonry and other obstructions were constantly encountered. The soil itself was made up of the rubbish of many epochs; and the contract demanded that traffic should not be interrupted on the streets above.

The standard section, inside the masonry arch and side walls, is as follows: Span at springing line, 29.52 feet; level of rail to springing line, 6 feet; rise of arch, 10.38 feet. The side walls

are 2.62 feet thick throughout, and the arch is 2 feet thick at the crown, increasing to 2.62 feet at the spring.

The conditions noted, and especially the unreliable character of the soil, necessitated the shield method of execution. The plan of attack adopted was to drive the side galleries, and in these timbered galleries to erect the masonry side walls as a support for the roof-shield to be used in excavating the remaining section. These side galleries were 6.6 feet wide at the top, and this top extended 2.3 feet above the springing line of the arch.

The roof-shield was practically the same in design as the one previously used so successfully at Clichy, in Paris. But in this case the shield was guided around the numerous curves by lateral rollers; and an important modification was made in the method of sustaining the soil behind the shield.

As shown in Fig. 75, the shield included a steel skin *A*, made of two plates each $\frac{3}{4}$ inch thick. This skin was supported by a double-latticed truss, with the ten hydraulic jacks located in the lower truss. It was provided with the usual front hood, cut away at an angle of about 45°. The latticed beam *H* tied the trusses together and formed the floor of the shield. As compressed air was not used, the shield was not fitted with a transverse bulkhead.

To guide the shield laterally in its forward motion, side rollers were provided, running upon planks of hardwood covered with steel plates, and attached to the masonry inside the side walls. These are shown in Fig. 75.

The method of sustaining the earth behind the shield was novel. Upon special latticed centering trusses provided, and held up by posts and braces leading to the center core of soil, latticed beams *e* (Fig. 76) were placed longitudinally and held in place by angle irons on the centering trusses. These longitudinal beams carried a series of small hydraulic presses *u*, with the upper end of the press buried in a timber *f* (Fig. 75b), which was about 8 inches thick and sheeted with steel plate on the soil side. These beams *e* were of different lengths, corresponding to the stage of construction in the arch

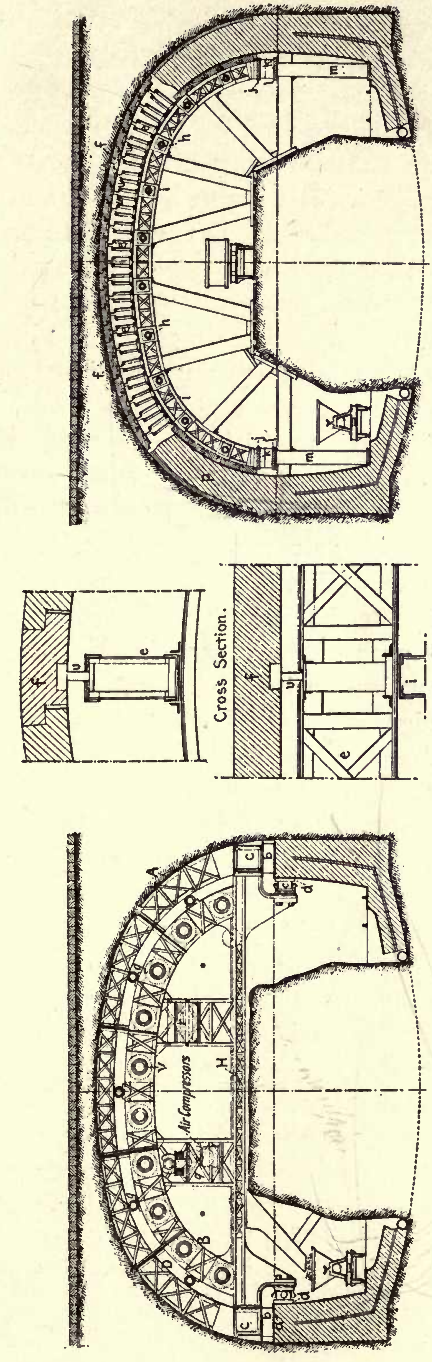


FIG. 75.—Roof-shield Used on the Orleans Railway in Paris.—*a.* Section back of the shield; *b.*—Details of the lagging supporting roof; *c.*—Section showing masonry construction, arch-centers and movable lagging.

masonry—the longest, 26.24 feet, being at the key; and the shortest, 9.84 feet, at the springing line. Small screws *g* running in the space between the latticed shield trusses were used in separately pulling forward the latticed beams *e* and the 8-inch timbers *f* attached to them, the beams slipping in the angle-iron guides. The greatest difficulty in using this method lay in the great friction encountered in hauling these members forward; but the French engineer believed, nevertheless, that this system possessed important advantages over the old method of building the masonry under a rear shield, as all necessary openings in the arch work are made easily.

The ten hydraulic jacks used in forcing the shield forward exerted a combined force of 1,000 metric tons. These jacks, instead of reacting upon the finished masonry, as usual, abutted against solid continuing struts passing through the centering system, as shown at *h* (Fig. 76).

In operating this roof shield, the shield was first advanced its length by the push of the jacks; the shield rolling on the rollers *b* placed under the beam *C* at the base of the shield. The sills and wedges are then laid for the new center which is erected to take the place vacated by the shield. The beams *e* and the 8-inch timbers *f* are pulled forward as the masonry advances; the small hydraulic presses *u* being operated to push up the timbers *f* into the space left by the advancing shield.

The arch masonry is built up at the haunches on small steel forms, and is continued on lagging held up by the same centering truss that holds the longitudinal beams *e*. The arch was constructed of beton blocks, molded and thoroughly set before they were brought to the work. Masonry was laid continuously, day and night.

Roof-shield of the Paris Metropolitan Railway.—This shield is interesting as embodying the latest practice of the French engineers in shield construction. The roof of the Metropolitan Railway of Paris is but little below the surface of the street; and the tunnel is a double-track structure with a clear span of

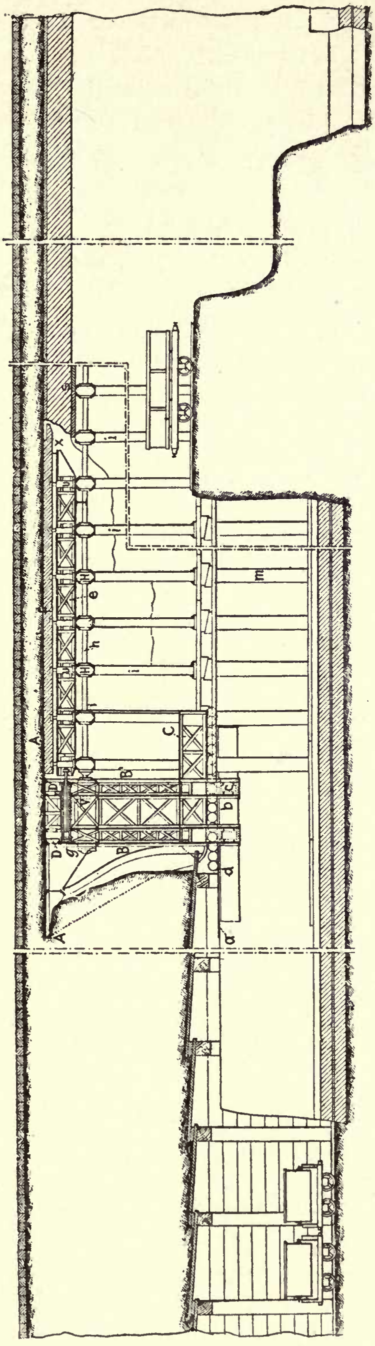


FIG. 76.—Orleans Tunnel, Paris: Longitudinal Section Showing Shield and Centering for Supporting the Soil in the Rear of the Shield.

23.29 feet and a rise of 6.79 feet in the arch. The arch, abutments and floor are all in masonry.

The first, or Vincennes-Maillot portion of this railway was partly constructed in 1898 by means of a modification of the Clichy sewer shield, previously here described. This was a half-section shield, on which the arch was built and the abutments constructed last, though in some cases the abutments were built in advance and the shield pushed forward on them. But the results were not satisfactory on the Metropolitan line, and much of the work was really done by ordinary methods of timbering. The failure of the shield was largely due to the fact that the soil penetrated was not homogeneous, being largely filled ground, with old foundation walls and broken masses of masonry interspersed through it. Then, too, in moving forward, the shield carried with it, around its outer surface, a certain thickness of earth which caused undulations in the surface ground, and by its broken condition threw too much weight on the tail-end of the shield. There was thus a tendency in the shield to rise at the forward end, while the fresh arch masonry was damaged under the friction of the shield when this was moved forward.

The shield here shown was devised by the engineers, Radenac and Raguet, especially to avoid these troubles, and in actual use it has been advanced as much as 20 feet in 24 hours' work.

The characteristic features of this new roof-shield are: Its length and the more stable support provided for the shield-rollers when the shield is moved forward. Instead of operating the rollers on top of freshly laid masonry, as is often done, the steel centers here employed are firmly braced together, and they are so supported and tied together at the bottom that they are practically immovable. As these centers carry the tracks on which the shield moves forward, this forward movement is steady and the surface settlements or undulations do not exceed three inches.

The shield is made of an outer sheet-steel shell, 15mm. thick and shaped to the extrados of the arch, and the total length of this shell is 7.5m. (24.6 feet). The shell is supported by four

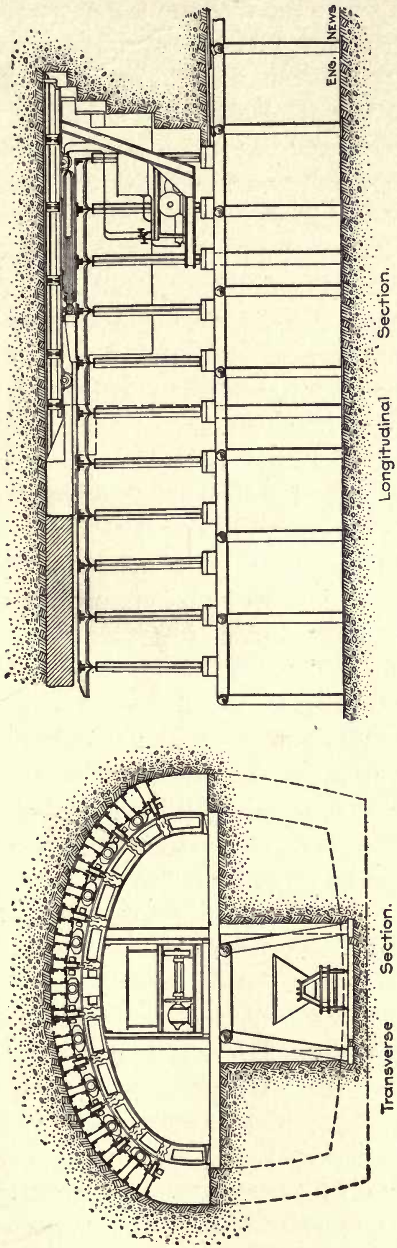


FIG. 76a.—Cross and Longitudinal Section of the New Shield Used on the Paris Metropolitan Tunnel.

cross-beams shaped to the shell and connected by 38 longitudinal girders, of which 20 extend forward to support the forward end, and 14 carry the rear end. As arranged the bottom of the shell is 0.68m. (2.23 feet) above the springing line of the tunnel and the forward end of the shell is shaped like a hood with four set-backs of about one foot each on each side of the axis. The shell is fastened to the girders by countersunk bolts, presenting a smooth surface outside. The webs of the girders are stiffened with angle-iron, making a box-beam of each pair of girders, or 19 in all. Ten of these box-beams support the rollers, and the 9 beams coming between them carry the hydraulic jacks. All of the members of this shield are connected by bolts in such manner that it can be readily taken apart after use, and the total weight of the shell and its framework is 67,540 pounds. The cast-steel cutters on the front of the hood are 8 in number, each about $3\frac{1}{4}$ inches thick by 6 inches wide, and these are bolted to the shield by $\frac{3}{4}$-inch bolts.

The centers upon which the rollers operate are built beams shaped to the arch and divided into two equal parts connected by means of bolts. The foot of this center extends about 18 inches below the spring of the arch, and it there rests upon a cross-tie made of two steel plates and angles. This tie is put in to obviate a tendency in the center to spread, and the whole center is carried on longitudinal sills supported by posts driven into the undisturbed ground of the lower advance gallery.

There are usually 30 of these centers under the shield and the finished masonry at one time; each center weighs about 1,980 lbs., and they are spaced one metre (3.28 feet) apart, c. to c. On top of this series of centers there is a projection in the axis of each of the 19 box-beams carried by these centers, and each center is connected to its mate by a series of cast-iron beams fitted with shoes and bolt-holes. The top of each of these connecting beams carries a rail 2.56 inches high, which is also the depth of the lagging to be used in laying the masonry on these centers. Arrangement is also made on these connecting beams for attaching the thrust-blocks of the hydraulic jacks.

The rollers are attached to the framework of the shell, and are set in 10 rows; the 6 rows in the middle having 6 rollers each, and the 2 rows on each side having 5 rollers. These rollers are made of cast-iron, double-flanged to prevent them running off the tracks, and with an extra width between the flanges so as to permit the guiding of the shield in its forward movement. Each roller is mounted on a $3\frac{3}{4}$-inch soft-steel axle, 16.34 inches long, supported in castings bolted to the frame.

The hydraulic jacks are each 8.8 feet long over all, and they have a stroke of 3.7 feet. While place was made for 9 hydraulic jacks, only 7 were actually installed, and 4 do all the work required. Each jack exerts a maximum pressure of 50 tons.

In operating this shield a bottom gallery is first pushed forward, and into this gallery is thrown the material excavated at the front of the shield. Before the shield is advanced, a new center-rib is set up and securely bolted to its predecessors, the roller-track for the shield being also lengthened by the span of the new center, or by one meter. The hydraulic jacks are fastened to the shell framework, and the pistons of the jacks act upon thrust-blocks set between the center-ribs. As these ribs are theoretically immovable, the shield-shell and its framework advance. As the shield moves forward, sheets of thin steel replace it and prevent the earth from falling in, and these plates are held in place by temporary timbering until the masonry is completed, the plates remaining in the ground.

The masonry is thus actually built behind the shield and not under it. The rear of the shield is shaped with two off-sets on each side, and the arch masonry is thus being laid with the abutment portions continually in advance of the crown of the arch. The masonry is built on wooden lagging laid upon the steel centers, and it completely fills the space between this lagging and the steel top-plates, the temporary props under these plates being removed as far as possible.

The crew for this shield work was made up as follows: One foreman and one machinist; 4 carpenters and 1 helper, to take down and put up centers; 4 miners, working at the face;

8 laborers, 6 shoveling and 2 attending to cars in the advance, lower gallery. In addition to these, 5 masons and 5 helpers were at work on the masonry; the masons working on the low wall that lies under the shield and along the springing-line on both sides in the intervals between advances of the shield. With the arch masonry complete, the two side walls and the floor of the tunnel are built by underpinning the arch as the bottom material is excavated.

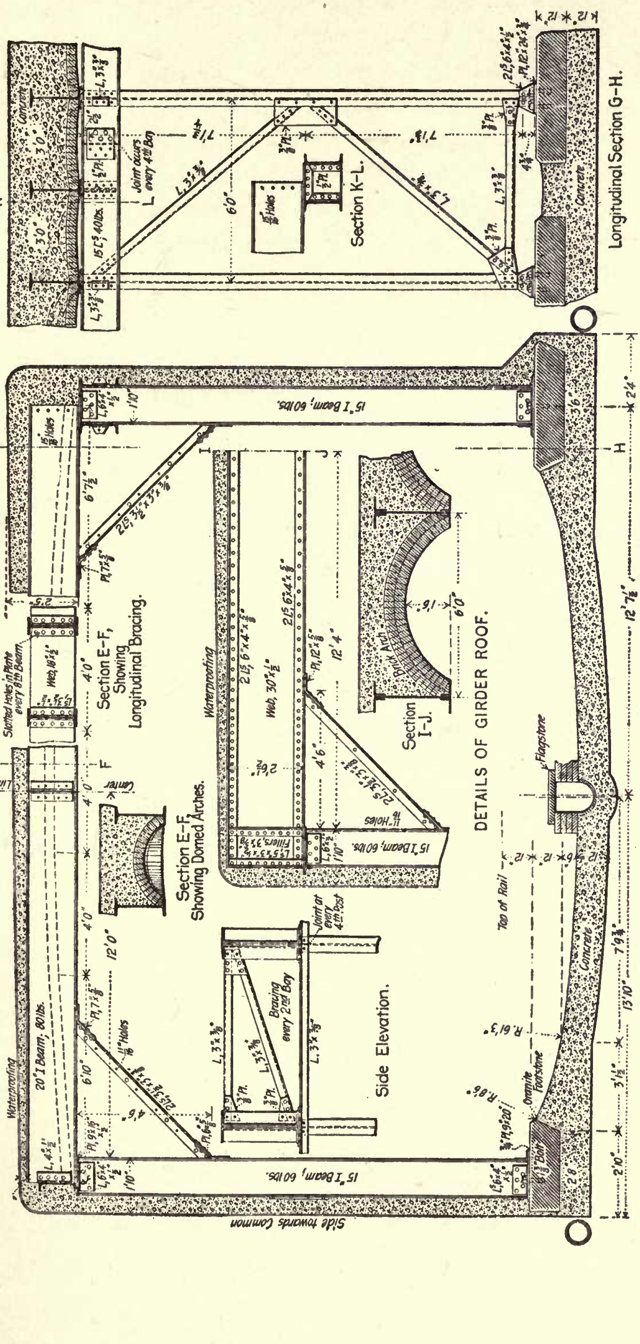
Boston Subway System.—Boston, a few years ago, had probably a more complicated and congested electric street-railway system than any other in the United States, and these conditions resulted in Boston being the first of our cities to construct a regular system of underground lines for its electric street-railway service.

Without entering into the detail of routes, it is sufficient to say the plan adopted by the Boston Rapid Transit Commission of 1895 contemplated the construction of about 5,600 feet of double-track subways, and about 3,500 feet of four-track subways. These subways were to be ventilated by fans driven by electric motors, and well lighted by electric lights. The chief engineer was Mr. Howard A. Carson, M. Am. Soc. C. E.

The material to be penetrated was mainly earth, sand and gravel, and the conditions were generally favorable, the maximum depth of excavation being 38 feet. The grades were 3% and 5%, and changes in direction, were made by curves of 700-foot radius on the center line.

As shown in Fig. 77, the general construction consisted of a concrete invert, side walls of steel columns with concrete filled between, and a roof of plate-girders or I-beams, with brick jack-arches between them, the whole covered by concrete. In the four-track lines a middle column supported the roof. The detailed dimensions are given in the illustration. The steel columns were spaced 6 feet apart, with a V-brace of 3 x $\frac{3}{8}$-inch angle-iron in each panel and a longitudinal tie at the base of the post made of a similar angle.

One of the ventilating chambers is shown in Fig. 78. It is a concrete chamber fitted with a ventilating fan driven by an



DETAILS OF TWO-TRACK SUBWAY WITH I-BEAM ROOF.

FIG. 77.—Boston Subway: Detail of Two-track Section with I-beam Roof.

electric motor, the air exhausted being discharged through an air-duct 6½ feet in diameter.

This subway was largely built in open cut, and this portion of the work requires no special explanation.

About one-third of the length of this subway is tunnel, with a concrete invert, side walls and haunching, and a brick arch, as shown in Fig. 79. The peculiar feature of this system of construction is the use of the tie-rods through the crown of the arch, intended to prevent any deformation of the arch due

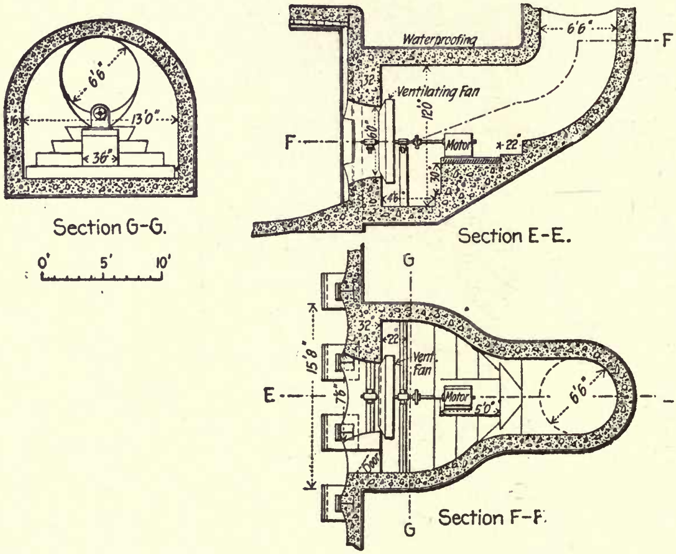


FIG. 78.—Boston Subway: Ventilating Chamber.

to eccentric loading, as the street surface is very near at some points.

In tunneling, the two side walls were built in advanced headings; the arch was then built by means of a shield supported on the side walls, and the center core of material was removed later. The concrete side walls are double. The outer wall, 6 to 12 inches thick, is backed directly against the sides of the excavation, and the inner face is then plastered with an asphalt composition to make it watertight.

For the tunnel section a roof-shield was employed of the type here shown. The position of the shield in relation to the tunnel section is shown in Fig. 80. The shield weighed about 22 tons and cost about $6,000. It was calculated to sustain an approximate load of 640,000 pounds. It was 29 feet 4 inches wide over all, and had a rise of 4 feet 4 5-16 inches. The shield is composed of two plate-girders 3 feet 8 inches deep and 4 feet apart, with cover plates extending 4 feet beyond the girder, while an additional top-plate extends 2 feet to the rear. Under each foot of each girder is an iron casting with a spherical projection on the under side, which fits into a recess in a cast-steel shoe, the surface in contact being planed to a truly spherical

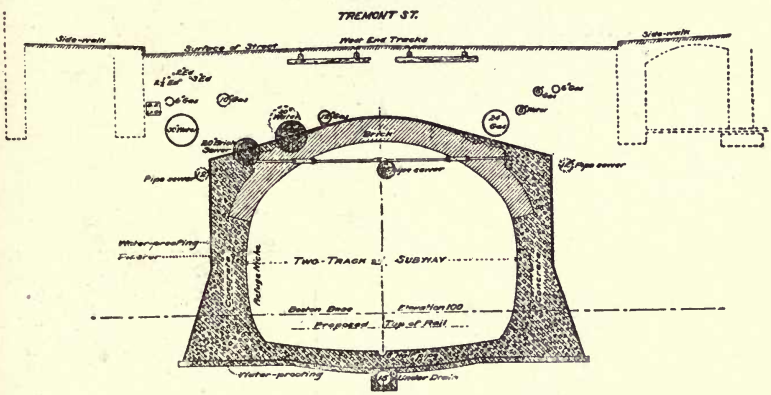


FIG. 79.—Typical Section of the Boston Subway, in Concrete and Brick Work; Double-track.

surface. These shoes rest upon two lines of 10-inch steel I-beams imbedded in the tops of the concrete side walls, forming a track upon which the roof-shield slides as it is pushed forward.

The girders are divided into 10 panels by transverse ⅜-inch webs, and a 6-inch hydraulic jack is located between the girders in each panel. The closed ends of these jacks are supported by the castings shown in the figure. The 6-inch plungers of the jacks pass through 10½-inch holes in the web of the rear girder, the outer ends of the plungers being fitted with collars, which latter abut upon 2¼-inch cast-iron round bars, about 2 feet 10

inches long, with $2\frac{1}{2}$-inch pipe-sleeves at the joints. These iron bars are built into the brickwork of the arch and form continuous lines of metal to resist the thrust of the jacks; a device apparently first used by Mr. Walton I. Aims in the East River gas tunnel, at New York.

In moving the shield forward the pipes leading to the jacks are brought under the rear of the shield, and they are fitted with valves, so that a man at this point can direct and regulate the direction of the advance by varying the pressure on each jack; men stationed at each jack watching and measuring the

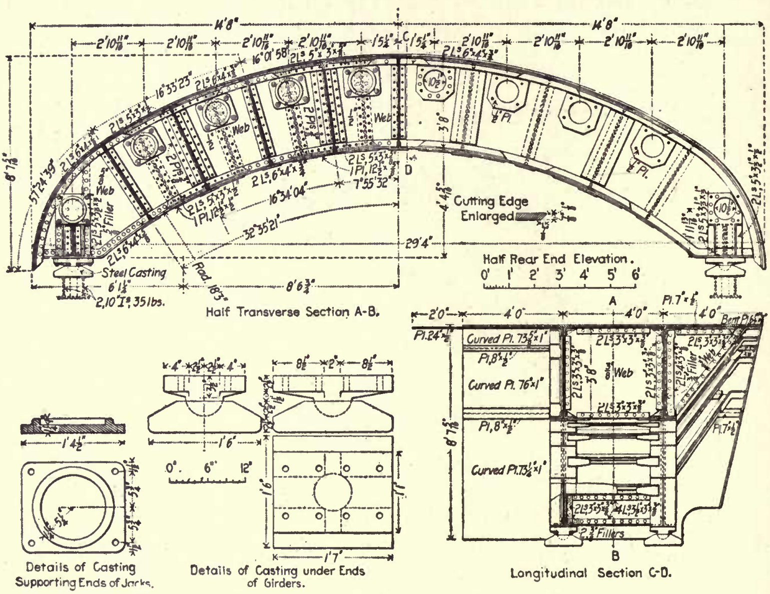


FIG. 80.—Detail of Roof-shield, Boston Subway.

advance simultaneously. As soon as the shield has been pushed forward about 3 feet the timber centering is erected behind it and the brick arch is built.

During this time a heading 6 feet high and the whole width of the tunnel is excavated ahead of the shield and supported by posts and poling-boards, which are removed as the shield reaches them. In the subway work in Boston the material was mainly gravel and stiff clay; the depth of earth above the tunnel

roof varying from 6 feet 9 inches to 13 feet. A progress of about 50 feet per week was made.

East Boston Tunnel.—The construction of the Atlantic Avenue station of the Boston Subway Extension, to East Boston, furnishes an interesting example of wide-arch, soft-ground tunneling. As shown in Fig. 82, this station is deep under ground and below the water-level, and at each end it connects with a standard double-track tunnel which is 23 feet 8 inches wide by 20 feet 8 inches high. The entrance shaft to the station is

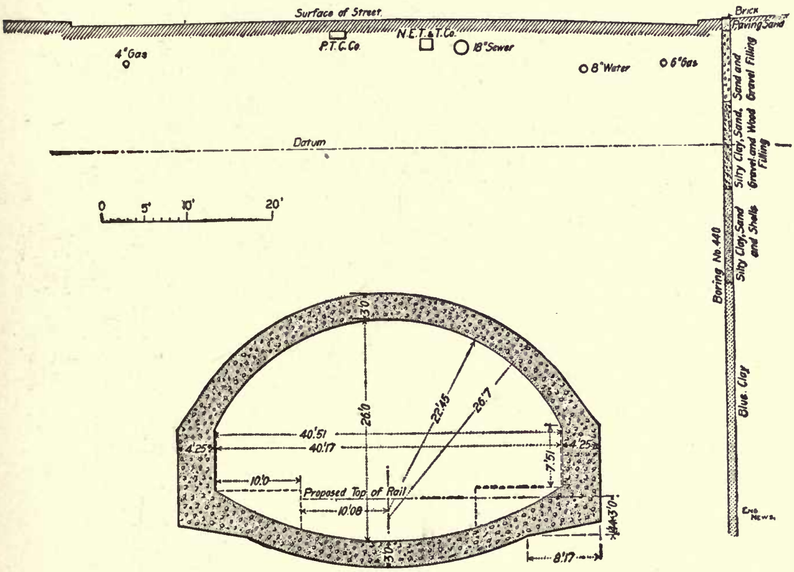


FIG. 82.—East Boston Tunnel; Atlantic Avenue Station.

40 x $57\frac{1}{2}$ feet in plan, and will contain elevators, stairways, etc., and this was built by sinking pits from the surface. The station portion proper is 150 feet long.

This station tunnel comes entirely within a blue-clay stratum, with occasional pockets of sandy clay. The side walls were built first, as shown in Fig. 83. A bottom drift was first opened and timbered as at *a;* the side boarding was then replaced by a lagging of corrugated boards, and behind this was built a 6-inch concrete wall, as shown at *b.* A portion

of the side wall and invert were then laid, as in *b* and *c;* and a second drift was started above the first and timbered, as shown by *e*, and in this drift the 6-inch concrete wall was carried up as before; the side wall was next carried up, as at *f*. This operation completes the wall to the springing line of the arch, both side walls being constructed simultaneously. It is understood that this side-wall work is a continuous operation. And it will be noted that the bottom drift—at track level—has a spoil-car platform.

The construction of the roof-arch follows close behind the

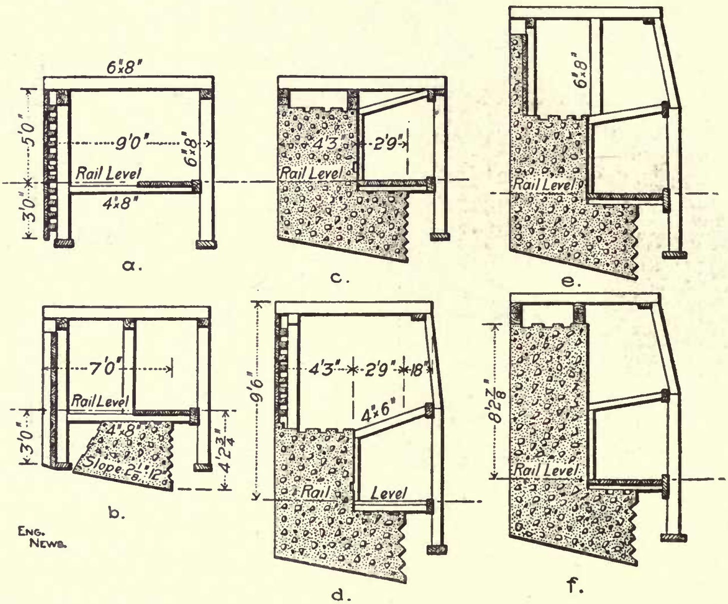


FIG. 83.—Sequence of Operations in Building the Side-walls at the Atlantic Avenue Station.

completed side walls, and the method of procedure is shown in Fig. 84. A crown heading *A,* 8 feet wide and $7\frac{1}{2}$ feet high, is driven and timbered, and over the caps are inserted four sheet-steel poling-boards. Ahead of *A* and below it, is driven a second heading *B,* 8 x 6 feet; this latter heading serves for the removal of the soil. From heading *A* a drift is carried right

and left toward the haunches, steel poling-boards being inserted and braced by radial struts from the core below. On each haunch and at the same time the drifts *D* are driven and roofed in a similar manner, working toward the springing lines. When drifts *C* and *D* meet an annular space is dug out, 30 inches deep, or the width of the poling-boards; in this space the concrete arch is built on centers in 30-inch sections.

The steel poling-boards referred to are made of No. 12 plate, 2 feet by 2 feet 6 inches in plan, and on each of the four sides is riveted a 2 x 2 x $\frac{1}{4}$-inch angle, each drilled for four bolt-holes, used in connecting the plates. In operation, four crown-plates

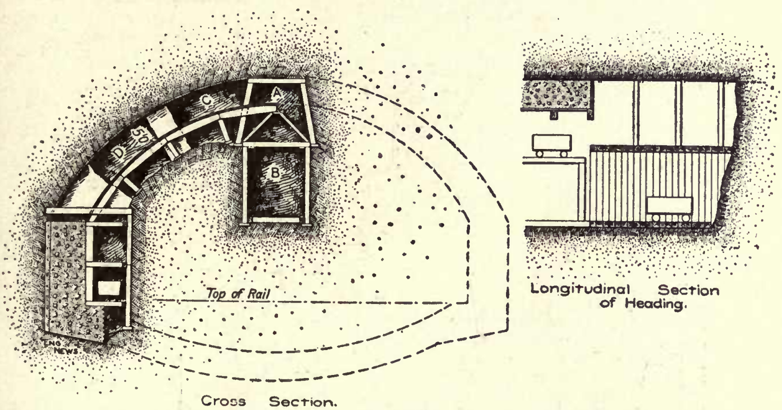


FIG. 84.—East Boston Tunnel; Atlantic Avenue Station: Method of Building Roof-arch.

are inserted endwise at the top of heading *A* and bolted together and to the rear plates. The lateral enlargement, 5 feet high and 30 inches wide, is roofed in a similar way for every 2 feet gained. Normally, the advance heading is kept about 10 feet in advance of the arch ring.

All the material from the headings *A* and *B* and the lateral drifts *C* is removed on muck cars running in the heading *B*; the spoil from the drifts *D* is passed down to cars in the bottom side drifts.

The arch-ring centers were built in 30-inch sections, and the lagging is left off the ribs at the crown. A special floor is con-

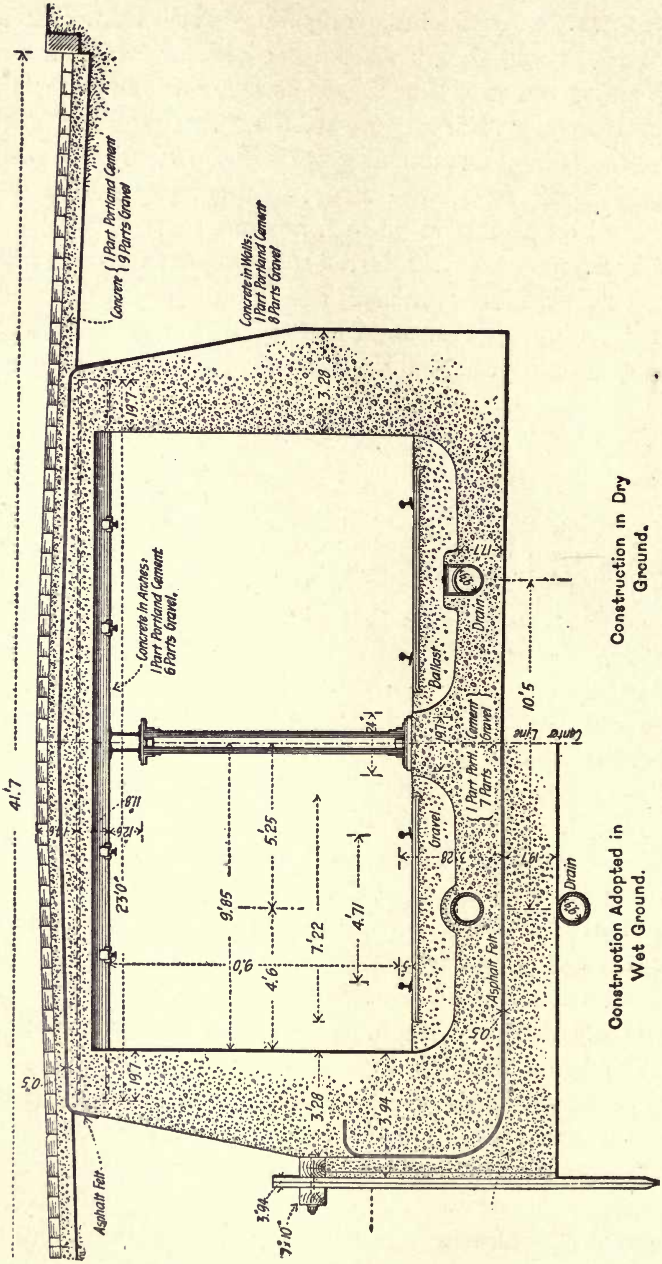


FIG. 85.—Buda-Pest Subway: Typical Cross-section.

structed for the concrete cars, as the arch work progresses, and at the level of the top deck of the shield through which the cars must pass on their way through the standard tunnel section. This is about 2 feet below the floor of heading *A*. The cars were dumped on this floor and the concrete was shoveled in by hand, working from the springing line to the crown. The key was built by passing the concrete in endwise over the forward center-rib. The steel plates were left in place. A 5-foot section of arch was constructed every 24 hours.

The earth core was removed as a final operation, from several benches; taking the material out under air-pressure and passing it through the air-locks. The invert was built in sections as this core was removed.

Buda-Pest Subway.—This line is historically interesting as being the first underground city railway operated by electricity. This double-track railway is about two miles long and runs under the center of a broad street. It was, consequently, constructed in an open cut in 1895; Siemens & Halske, of Berlin, designing the electrical equipment.

The typical cross-sections shown in Fig. 85 are those of a dry-ground section and a deeper section where the excavation penetrates below the water-line in the ground. In the latter case every precaution has been taken to exclude water from the subway. The asphalt felt employed for this purpose was applied in sheets in two layers, each sheet being about 31½ inches wide and laid to break joints. On the under side these sheets were painted with a sticky natural asphalt, and the upper side was coated with fluid asphalt.

The invert shown was only used for a short distance, where ground-water was encountered. The drain-pipes under the center of each track drain into small reservoirs at each station, where the water is pumped from them by small electric pumps.

New York Rapid Transit.—Without entering into the detail of the history, route, etc., of the Rapid Transit Railway now nearing completion in New York, some of the standard cross-sections are here given.

The plan and section of the four-track subway shown in Fig.

86 requires little explanation. The same type of construction applies to the bulk of the two and three-track sections. The form is rectangular, and it is made up of transverse bents of steel columns and roof beams, with side walls, roof and floor of concrete. The interior columns are built up, while the side

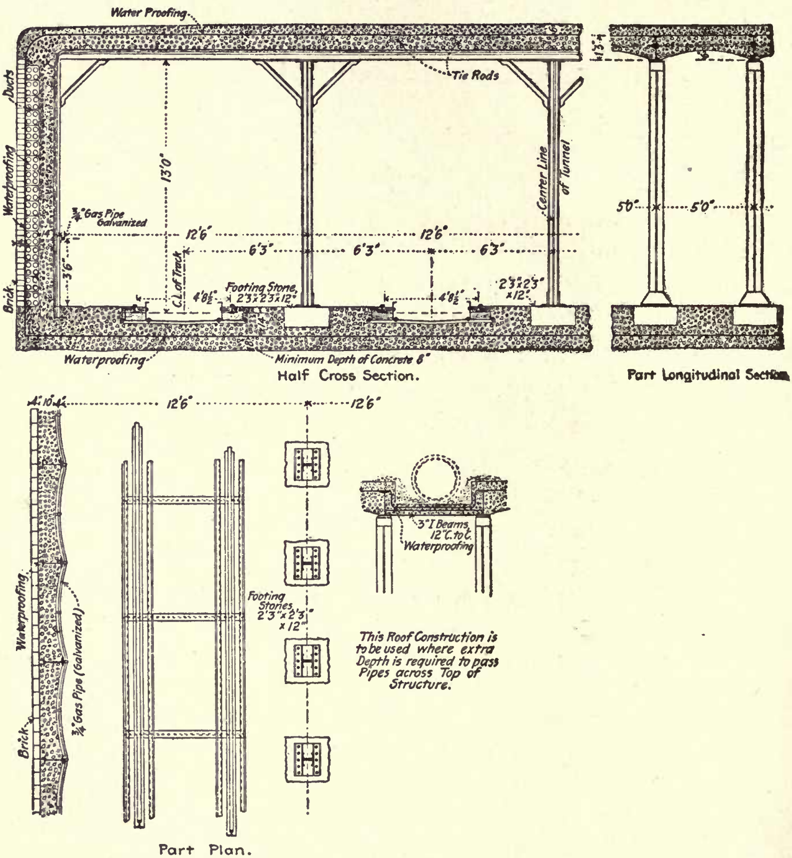


FIG. 86.—New York Subway: Plan and Section, Four-track Line.

columns are I-beams; the roof is supported by rolled I-beams. The entire four sides of the section are preserved from seepage by a layer of waterproof material imbedded in the concrete.

The double-track rock and earth sections are 25 feet wide

in the clear and 18 feet high at the crown, as shown in Fig. 87. In each case the tunnel is lined with concrete.

Open-cut Work, New York Rapid Transit Railway.—As an illustration of deep open-cut work in subway construction, a sketch plan is here given showing the method adopted in building a portion of the New York Rapid Transit Railway.

In this section the subway excavation had to be made unusually wide to provide for the station and a fifth or switching-track. The excavation extended to a depth of about 35 feet, with the bottom 10 to 15 feet in rock.

The sequence of operation was as follows: The trench *A*

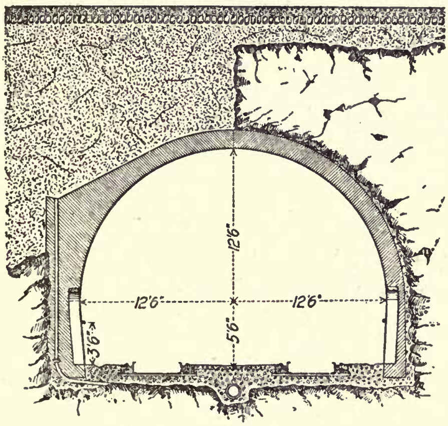


FIG. 87.—New York Subway: Standard Earth and Rock Sections.

was first opened on the south side of the street down to subgrade and wide enough to permit the erection of two bays of the steel work. This trench was sheeted and braced in the usual manner, and the two bays of the tunnel were completed. The next step was to start the transverse drifts *B*, each about 12 feet wide and 50 feet apart, and long enough to reach beyond the column of the fourth bent of steel work. The top of these drifts was kept well above the subway roof line and the bottom was carried to the rock, each drift being well timbered and sheeted. When a number of these drifts had been completed the north ends were connected by the longitudinal drift *C* with

the same top and bottom level as the transverse drift. Then these drifts *B* and *C* were deepened through the rock to subgrade, and the concrete floor was laid in *C*, and on this was erected the fifth row of columns.

The next operation was to widen drift *B* so as to permit the placing of the 25-foot roof beams connecting the third and fifth rows of columns. This widening was done by breaking down both sides of the drift under poling-boards driven ahead and supported by vertical posts until the headings met and left

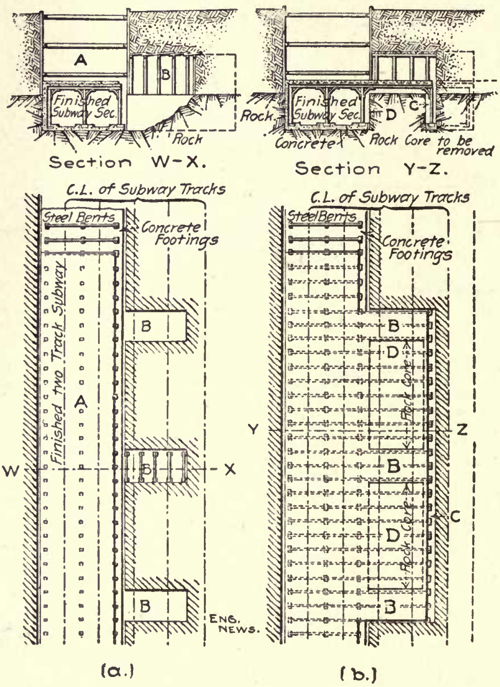


FIG. 88.—New York Rapid Transit Railway: Sketch-plan Showing Method of Excavation East of Fifth Avenue.

the entire space between the drifts open, as indicated at *D*. The roof beams were then erected and the rock core was removed to subgrade. After this was done the concrete floor was put in and the fourth row of columns was set up. To excavate for the fifth bay the original transverse drifts *B* were widened out until the entire space was cleared.

As fast as the subway roof was built, brick or rubble walls or piers were erected over the roof beams to support the poling-boards, and all open spaces were packed with earth and stone. The spoil was removed on a track laid in the bottom of trench *A*, with transverse tracks laid in the drifts *B* connecting by turn-tables with the main track. At intervals holes were left in the subway roof, and through these the muck was lifted by a Carson-Lidgerwood cableway and deposited in carts on the street surface. The final operation was to backfill the trench *A* and restore the street surface.

On another portion of this line, with depth of excavation

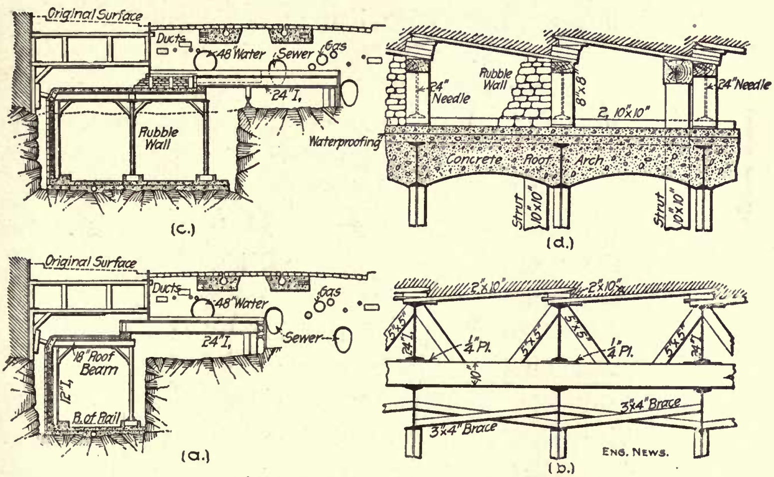


FIG. 89.—New York Subway: Sketch-plan Showing Method of Work Between Fifth and Sixth Avenues.

varying from 25 to 39 feet, and the lower 10 to 27 feet in rock, a somewhat different method of construction was followed.

The opening trench, 20 feet wide, was sunk to subgrade and in this the south bay of the tunnel was erected and completed, except for some holes in the roof for extracting material.

At intervals of about 100 feet transverse drifts, 12 feet wide, were driven to a point about on a line with the third row of columns. This drift was sheeted and timbered and had its top well above the roof line and its bottom on the rock. A pair of

10 x 10-inch beams was then laid on the subway roof, about over the second row of columns, to form a support for the rear ends of three I-beam needles which were inserted endwise in the drift, about 5 feet apart. The front ends of these I-beams were supported by posts resting on the rock bottom. Wedges were inserted between the roof-sheeting of the drift and the tops of the I-beams, and these were driven tight so as to take the load off the temporary drift struts and transfer it to the needles; the temporary struts were then removed.

The drifts were then widened by removing the side sheeting and breaking down both walls. The excavation was carried on under roof poling-boards driven over the top flanges of the needles. When the excavation had proceeded about 6 feet, another I-beam needle was inserted parallel to the first and supported in a similar manner. The excavation was continued in this manner until a sufficient space had been provided to permit the excavation of the rock bottom of the drift to sub-grade, and a second bay of the tunnel was then erected. The widening of the drifts finally cleared the whole space under the needles, and the second bay was made continuous.

To clear the space for the third bay the original drifts were extended and strutted, as before, well beyond the line of the fourth row of columns. Rubble walls were first built on the roof of the subway to support the roof poling-boards. A timber was then placed parallel and close to each of the three I-beams and was jacked up until it took the roof load off the needle. The three I-beam needles were then slid forward into the extension of the drift until their rear ends rested on the pair of 10 x 10-inch timbers now placed over the third row of columns. The needles were supported and the drift widened as before. The building of the fourth bay was simply a repetition of the process.

Atlantic Avenue, Brooklyn, N. Y.—The Atlantic Avenue section of the Long Island Railway is having its tracks depressed and put into a subway. The standard plans adopted for this subway are here shown in such detail that little description is necessary.

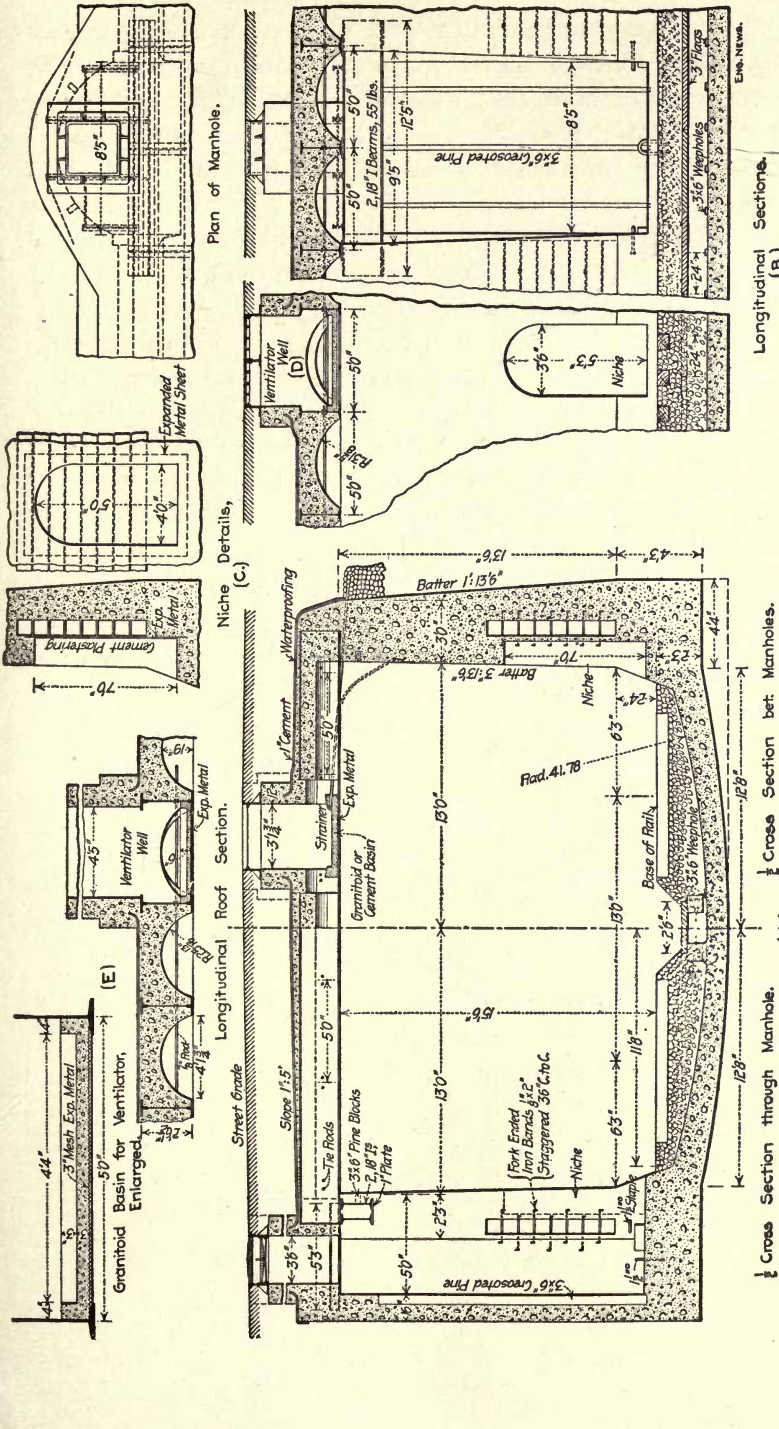


FIG. 90.—Atlantic Avenue Subway, Brooklyn, N. Y.

The invert, side walls and roof are made of concrete. The 5-foot arches forming the roof are supported by transverse I-beams, and the top is then waterproofed as follows: After the concrete has thoroughly set and is well dried out by the sun, the upper surface "is swabbed over with hot, melted, medium hard coal-tar pitch of a somewhat softer grade than that used for roofing purposes, or such as will soften at a temperature of 60° F., and melt at a temperature of 100° F." In this pitch the oil distilled from it shall have "a specific gravity of 1.105." The pitch is put on until it has a uniform thickness of not less than 1-16 inch. Immediately upon the first coat and while it is still melted, is laid a covering of single-ply roofing felt, lapping at least 4 inches on all cross-joints and at least 12 inches on all longitudinal joints. The felt is at once covered with a uniform thickness of the pitch, and upon that is laid a second covering of roofing felt, which is also covered by not less than 1-16 inch of pitch. This waterproofing extends over the ends and down the sides, as shown on the cross-section. After the waterproofing is thoroughly hardened a 1-inch layer of Portland cement mortar is uniformly spread over it with a trowel. This mortar is laid in 5-foot squares, alternately, for the purpose of providing for expansion and contraction.

At intervals of 30 feet ventilator wells are provided leading to the street surface, and at intervals of 15 feet refuge niches are built into the concrete side walls. At every 900 feet special niches are made in which to install the electro-pneumatic signals for train operation. The side walls contain throughout their entire length imbedded ducts for electric wires, with manholes at intervals in which the ducts terminate.

CHAPTER IX

SPECIAL TUNNEL-BUILDING PLANT

Cascade tunnel plant—Scraper-loading—Automatic dump at shafts—Dumping wagon—Cement-mortar car—Walker's detaching hoist-hook—Concrete-mixer.

The success or failure of a contractor depends largely—if not entirely—upon his experience and skill in organizing his working force, and upon the intelligence he displays in devising or adopting means for reducing the labor cost of work performed, and at the same time hastening completion. This contractor's plant covers a multitude of items, the bulk of which are familiar to both engineers and contractors. But nearly every large work also demands special appliances for expediting or cheapening work, and some of these appliances are here illustrated and described, rather as a hint to the contractor than as an attempt to describe the multitude of devices of this nature used in American practice.

Special Plant at Cascade Tunnel.—In an article upon this tunnel John F. Stevens, M. Am. Soc. C. E., then chief engineer of the Great Northern Railway, describes some of the special plant employed.

The tunnel itself is in rock, single track, 13,813 feet long, with the section shown. In excavation the arch section was first taken out to the full section of 10 x 20 feet, and the bench was removed in two lifts.

To facilitate the removal of rock from the heading and the top lift of the bench, a traveling platform, or "jumbo," was erected, as shown in Fig. 91; the broken rock being wheeled onto this and dumped through chutes into the muck-cars which could run beneath it. To load large masses of rock onto flat-cars, a 6-ton capacity hoisting plant, run by compressed air, was

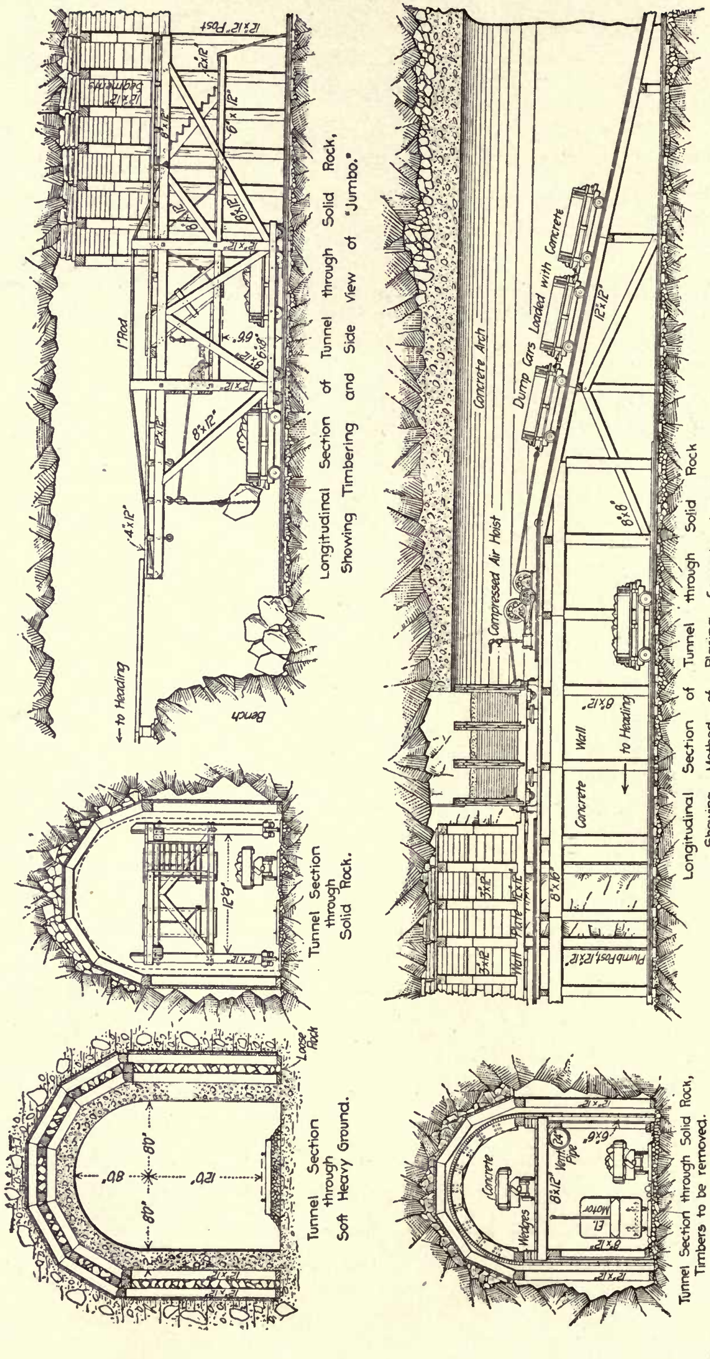


FIG. 91.—Cascade Tunnel: Showing Sections of Tunnel and Excavating and Lining Systems.

installed on a platform beneath the main platform of the "jumbo." This same hoisting engine was employed in moving the "jumbo" back from the face during a blast.

This tunnel was lined throughout with concrete, nowhere less than 24 inches thick, only such timbering being allowed to remain as it was unsafe to move. As it was imperative that the placing of the concrete should not in any way interfere with the driving of the tunnel a special concreting apparatus was devised, as shown in Fig. 91. This platform was erected in sections 500 feet long, and it was reached by an incline up which the concrete cars were hauled by an air-hoist and cable. While each 500 feet of tunnel was being concreted, the advance 500 feet of platform was being erected with its own incline. The side walls were built in sections of 8 to 12 feet in length, the weight of the timber arch being gradually transferred from the plumb posts to the side walls. The arch sections were 12 feet long, 4 x 16-inch plank being used for the center-ribs. As each 12 feet was completed, the centering was advanced bodily 12 feet on dollies and jacked up to the proper elevation. The concrete was mixed on planks installed at each portal, the proportions being 1 part Portland cement, 3 parts sand, and 5 parts broken rock. The concrete cars were hauled to the foot of the incline by electric motors. The average monthly progress of the concreting was 1,115 lineal feet of tunnel; the best daily progress was 32 feet.

All hauling out of muck and hauling in of concrete was done by electric motors. Eight of these motors were in service, and one of these motors hauled trains of 16 to 20 loaded dump-cars of 1 cubic yard capacity each; it did this up a 1.7% grade at a speed of 10 miles per hour. The track was double, 2-foot gage, laid with second-hand 50-lb. rails on wooden ties. The track system was equipped with split switches, electric target-lamps, etc., and Mr. Stevens ascribes much of the success met with in hauling the material such long distances to the care exercised in the installation of this track and to the heavy material used in building the muck-car trucks.

Nearly 1,000 16 c. p. electric lamps were used in the tun-

nel, boarding camps, offices, etc. Electricity was generated by eight dynamos aggregating 300-kw. minimum capacity. These dynamos were driven by four automatic high-speed steam engines.

The foul air was exhausted from the headings through a 24-inch galvanized iron pipe by means of a No. 9 Sturtevant fan, running at 1,700 revolutions per minute. These exhaust pipes were made in 16-foot sections, bolted together by cast-iron rings with friction-paper washers between the rings. As a rule the ventilation was excellent, from 10 to 20 minutes being sufficient to clear the heading after a blast. The large amount of air liberated by the drills, hoists and pumps added materially to the supply of fresh, cool air.

At each portal large power houses were erected. The plant at the east end included:

1	Ingersoll-Sargent duplex compressor	18 x 24 ins.
1	Rand duplex Corliss valve compressor	20 x 36 ins.
1	Buckeye high-speed engine	12 x 16 ins.
1	Chandler & Taylor high-speed engine	13 x 14 ins.
6	150 horse-power boilers.	
	Pumps, water heaters, dynamos, fans, etc.	

At the west portal the plant included:

1	Ingersoll-Sargent duplex compressor	18 x 24 ins.
1	Buckeye high-speed engine	12 x 16 ins.
1	Chandler & Taylor engine	13 x 14 ins.
3	150 horse-power boilers, with pumps, etc., as above.	

The compressed air was carried to the work in a 6-inch wrought-iron pipe, and distributed at the headings, through manifolds, to the drills, air hoists, pumps, etc.

The pumps, driven by compressed air, were in duplicate, to avoid delay or danger from accident. The considerable annoyance caused by the freezing up of the air-valves of the pumps was partly eliminated by the introduction of traps; but this trouble was not serious enough to warrant reheating the air. During the last year of the work at the east end over one mil-

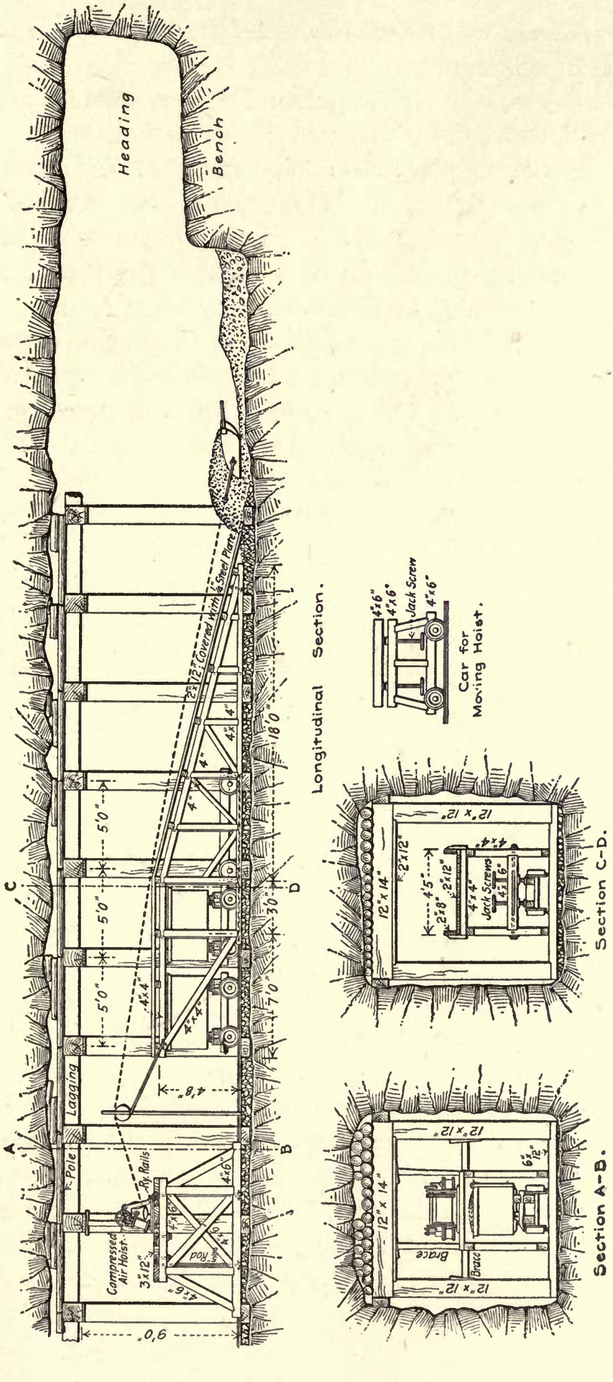


FIG. 92.—Scraper-loading Device Used in the Kellogg Tunnel.

lion gallons daily was raised 110 feet vertically through 6,000 lineal feet of 8-inch pipe.

Scraper Loader.—In driving the Kellogg tunnel, at the Bunker Hill & Sullivan Mines, in Idaho, a scraper was used for loading the debris into dump-cars. This is described as follows by Ulysses B. Hough, the engineer of the mines:

The tunnel section was 11 feet high and 9 feet wide in stable rock; 9 feet high by 8 feet wide in the clear, in timbered sections. As the tunnel was about 9,000 feet long every effort was made to insure rapid progress. Hand shoveling was tried —by day's work and by contract—with little difference in result in removing the blasted rock, and the device here shown was then installed.

A single-drum, double-cylinder Bacon hoisting engine was mounted on a wooden frame arranged to permit the passage of dump-cars beneath it, these cars holding 1 cubic yard of rock. In front of this frame was another frame with an inclined floor toward the heading. The level end of this frame would allow two cars to stand under it, and over the car nearest the hoist was an opening in the floor. A No. 1 scraper was employed in hoisting the debris up the incline and to this opening, two scraper loads usually filling a car. When the first car was loaded it was pulled forward and the second car was filled in like manner. Trains were made up 50 to 100 feet beyond the hoist.

The gang included five men: One at the hoist, one at the dump-cars, and three loaded and attended to the scraper. In 2½ hours these men moved 40 to 50 cubic yards of waste, or about 18 cubic yards per hour.

The loading platform was moved by a special car, fitted with four jack-screws; this was run under it and the frame was jacked up until the weight rested on the car; the frame was then pushed back to permit the laying of new rails. The hoist was moved in a similar manner. The jack-screws on these cars were made of worn-out drilling machine feed-screws. The five men usually moved both frames in five minutes. After

using these frames for fifteen months they were both still in good condition.

To remove the rock from the tunnel a 4-ton General Electric Company's motor was used. This motor ran on a 24-inch gage track; and it hauled 15 to 20 cars at a time on a grade of 0.5 foot and 0.3 foot per 100 feet. The rails weighed 30 pounds to the yard.

The smoke and gases from the working heading were removed by a No. 9 Sturtevant fan, exhausting the air through a 22-inch pipe made of No. 18 galvanized iron. This pipe was made in 18-foot lengths, with all seams riveted and soldered.

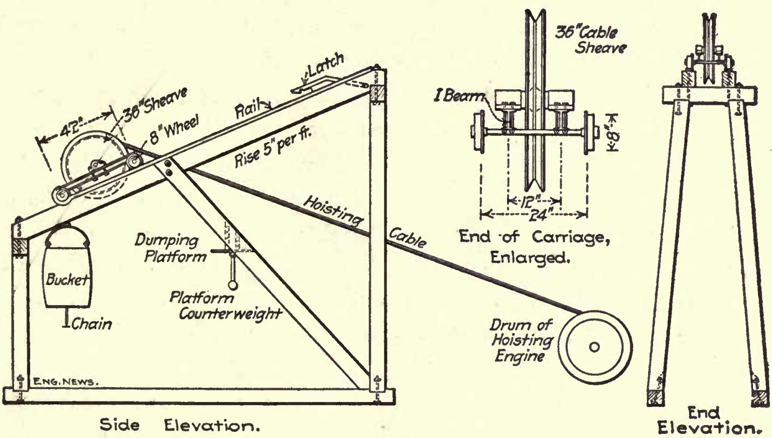


FIG. 93.—Automatic Dump for Shafts.

The joint was made by inserting one pipe in the other, wrapping heavy sheeting about the joint and painting with coal-tar. This plan removed the gases from the heading in 15 to 20 minutes, even with 8,000 lineal feet of exhaust pipe in use.

Automatic Dump for Shafts.—Fairbanks, Morse & Co., of Chicago, Ill., manufacture an automatic device for tripping and dumping buckets at the head of a shaft, reducing the amount of labor ordinarily required.

Instead of the usual form of head-frame, with fixed sheave above the mouth of the shaft, this frame is made, as shown in Fig. 93, with an incline of 5 inches to 1 foot. Upon this

frame is mounted a steel traveler carrying the main hoisting sheave.

When the bucket is being hoisted, the traveler is at the lower end of the incline, held by the rails bent upward to form a stop. When the bucket is clear of the shaft a stop prevents it from rising too high; but the winding of the cable continues and the traveler is hauled up the incline and is automatically caught and held by a pair of latches. The cable is then paid out and the bucket is lowered to the dumping floor. This platform has in it a slot to receive a loose chain attached to the bottom of the bucket and carrying a disk or ball at its end. The weight of the bucket tilts the platform and the bucket is inverted, being held to the platform by the ball. The empty bucket is then hoisted again and the latch is released, the carriage runs to the front of the incline and the bucket descends. The device is controlled by the one man at the hoisting engine.

Dumping Wagon.—The illustration sufficiently shows the construction of a special dumping wagon, made by the Shadbolt Manufacturing Company, Brooklyn, N. Y. In this wagon the body is balanced over the hind springs, so that it is easily tilted without the use of any mechanism, the springs resting on a bar across the frame. This bar pivots in steel sockets and

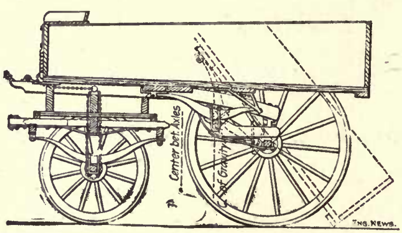


FIG. 94.—The Shadbolt Dumping Wagon.

turns with the body; and the sockets are set in the frame sides a sufficient distance in front of the rear axle to throw a proper proportion of the load on the front axle.

In dumping, the chain passing around the front axle takes up some of the jar, prevents the body from striking the ground at the rear, and at the same time this chain automatically pulls

the hook out of an eye in the tail-board and releases the latter, which is pushed open by the load. This wagon was successfully used in building certain sections of the New York Rapid Transit Railway.

Cement Mortar-car for Lining Tunnel.—The Mullan tunnel, on the Northern Pacific Railway, was relined with masonry in 1894, to replace the old timber lining. H. C. Relf, C.E., describes this work, and from his paper in the *Journal of the Association of Engineering Societies,* for August, 1894, the following matter is taken relating to some of the plans used.

The tunnel is 3,850 feet long, single-track; the clear dimensions in the lined tunnel being 16 feet wide and 20 feet high at the crown. The masonry includes concrete side walls, 24

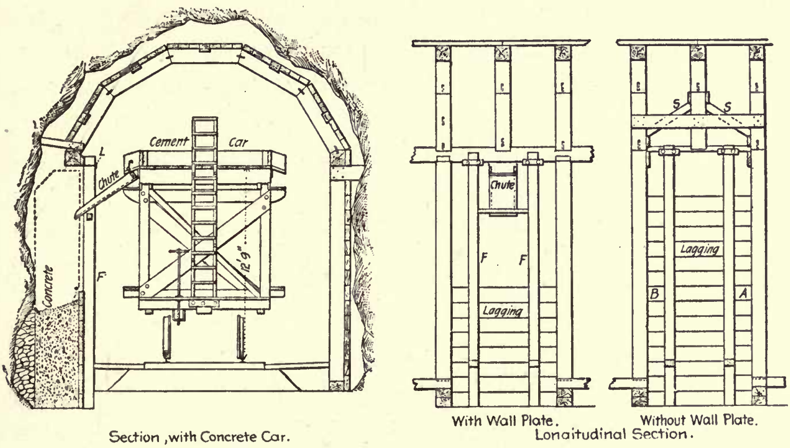


Fig. 95.—Mullan Tunnel: Cement-mortar Car, and Timbering Used in Relining Tunnel.

inches thick, surmounted by a full center arch of three to four rings of brick. This required the removal of all the old timber lining.

The work was done in 7-foot sections, by first removing one post and supporting the 5-segment arch of 12 x 12-inch timbers by the struts *S S,* Fig. 95. After clearing away any backing and excavating for the foot walls, two temporary posts *F F*

were set up and fastened by hook-bolts, and a lagging was built to hold the concrete. Several of these 7-foot sections were prepared at a time, each being separated by a 5-foot section of the old timbering.

The cement-car shown was then run in, and by means of a chute enough cement mortar (1 cement to 3 sand) was run into each section to make an 8-inch layer of concrete. As the car passed on to the next section, enough broken stone was shoveled into the 8-inch layer to take up all the mortar. The walls were thus built in 8-inch layers, and in 10 to 14 days they were sufficiently set to hold the arch. The wooden arches were then allowed to set on the new walls, and the remaining 5-foot sections were cleared of timber and in a similar manner filled up with concrete. The average progress was 30 feet of side wall in one working day; or about 45 cubic yards, costing $8 per yard; including in this cost all labor in removing old timber, train service, lights, tools, engineering, superintendence and interest on plant.

The brick arch was built up on a 5-segment center supported by posts, wall-plates and sills. This arch was built in 3 to 9-foot sections, depending on the ground. The cement-car was used for mixing the mortar. This brickwork cost $17 per cubic yard; and the total cost of the new lining was about $50 per lineal foot of tunnel.

Steam-shovel Operated by Compressed Air.—In driving a double-track tunnel through gneiss and mica-schist, at St. Mary's Park, on the New York Central & Harlem River Railroad, the muck in the tunnel was handled by a steam-shovel operated by compressed air.

The rock was removed by first running a top-heading, 8 x 12 feet, through the tunnel, and then taking out the remaining rock in two lifts, working from the top down. Two rows of holes were drilled in each bench and charged and fired in sequence, using 6 pounds of dynamite or joveite to the cubic yard of rock.

The heavy muck heap resulting was attacked by a Marion Model No. 20 steam shovel, equipped with a 1-yard dipper.

This shovel was hauled out of the way of blasting by a cable, operated by the same hoisting engine that handled the muck cars on a track laid parallel to the shovel track.

The muck cars had a capacity of about 5 cubic yards, and they averaged about $2\frac{3}{4}$ cubic yards of solid rock per load. These cars were hauled out of the tunnel in trains of two cars, up an incline having a sufficient grade to run the empty cars back again. The muck was lifted in skips by a derrick located on the side of the approach cut, and was either dumped into cars, or on a heap for use in concrete making.

The compressed air was furnished by the rock-drilling plant,

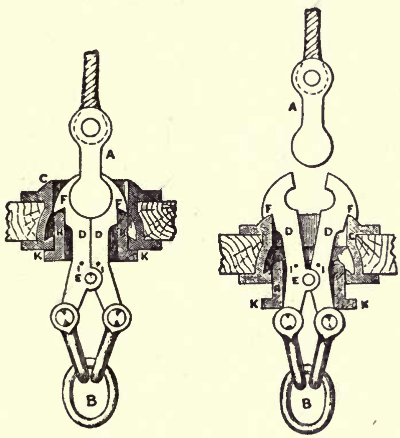


FIG. 96.—The Walker Detaching Hook for Shaft-hoists.

and the shovel gave perfect satisfaction in its working in the tunnel. Its crew consisted of two shovelmen, four pitmen, and a pit boss.

Walker's Detaching Hook.—A frequent source of danger in shaft hoisting is the overwinding of the cage, due to carelessness or accident. To obviate this danger, the Walker detaching hook is now largely used in England.

In this hook the lifting rope is attached to the shackle *A*, and the cage is hung from the connecting link *B*. The supporting ring *C* is a fixture in the beam at the top of the head gear. The two jaws of the hook work on a center pin *E*, in such manner

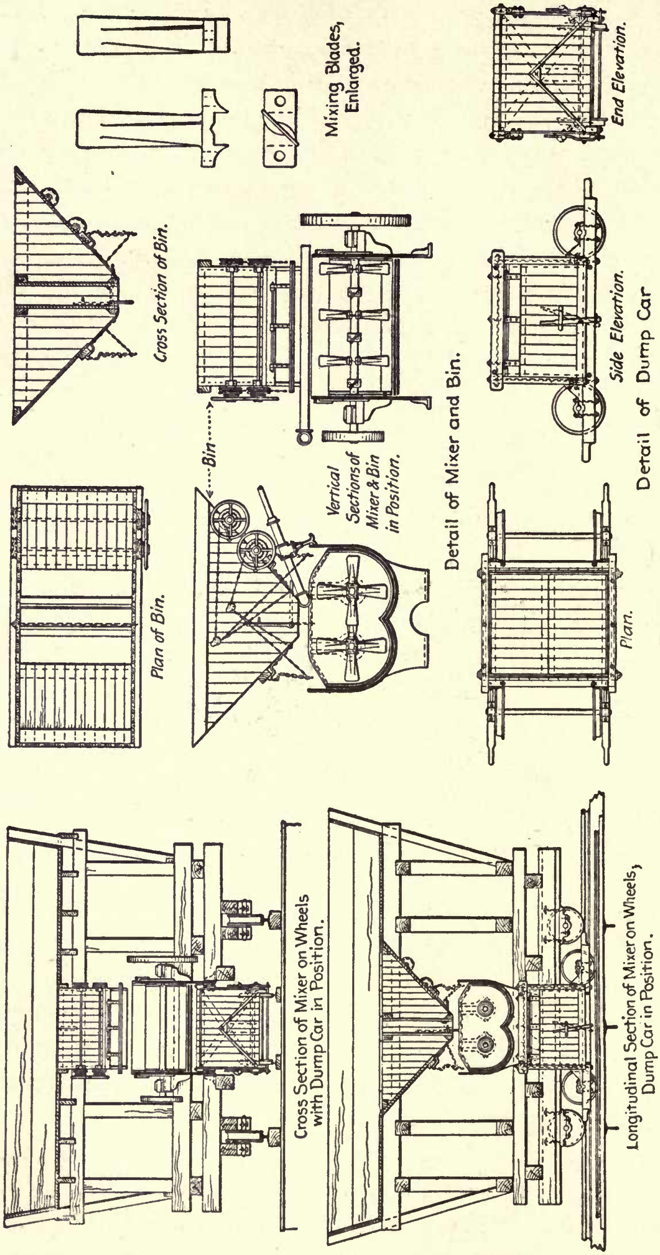


FIG. 97.—Concrete-mixing Plant: New Orleans Drainage.

that, in case of overwinding, the load tends to open the jaws and release the center pin of the shackle *A;* though, ordinarily, the clamp *H* keeps the jaws together.

In case of overwinding, the jaw-hooks pass freely into the ring *C;* but the projection *K* on the clamp *H,* on coming in contact with the bottom flange of *C,* holds the clamp stationary and allows the jaws to be pulled through the ring *C.* In doing this two small pins *I I* are sheared off, and the jaw-hooks open and catch on the ring *C,* holding the cage, and at the same time releasing the shackle *A* and the winding rope attached to it.

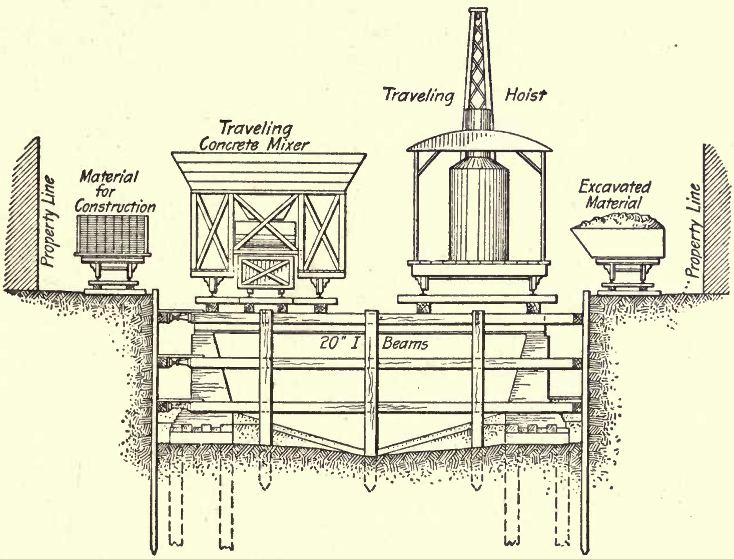


FIG. 97a.—Cross-section on St. Louis Canal, Showing Arrangement of Machinery During Construction.

Concrete Mixer, etc.—In the construction of the lined and covered canals for the improved drainage of New Orleans, La., the comparatively narrow streets of the old city required special disposition of the necessary plant.

The cross-section of the canal on St. Louis street (Fig. 97a) shows the general arrangement adopted for taking away the excavated material and bringing in the material of construction.

The concrete mixer employed was arranged to run on a

track of 8-foot gage, supported by the brace timbers. Beneath the mixer was a 30-inch track carrying small side-dump cars, of a capacity of 18 cubic feet each. The mixer itself consisted of a heavy cast-iron box, in which revolved in opposite directions two mixing paddles. The dry material was shoveled into the gaged hoppers and dumped directly into the mixer through bottom doors operated by levers. The sand and cement came from the material yard in skips, these latter being filled from the cars by a 3-ton American hoist traveling derrick. This derrick was also used for lifting the bricks required and hand-

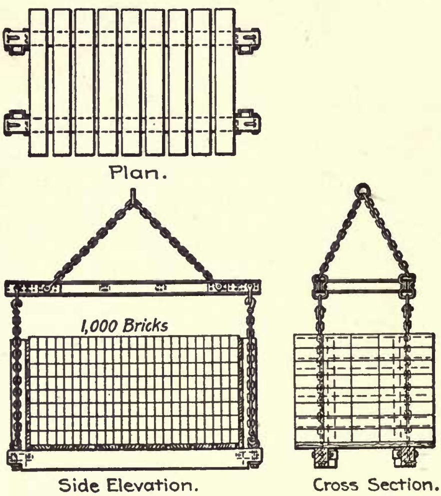


Fig. 98.—Crates for Handling Bricks.

ling the heavy roof beams, which, in the larger canals, weighed one ton each. The trains to and from the work were operated by an electric trolley system.

The bricks were made near Lake Ponchartrain. And as these bricks were taken from the kilns they were piled on special crates (Fig. 98) holding 1,000 bricks each. These crates, with the bricks, were picked up by a derrick and loaded upon barges, each barge carrying 100,000 bricks. This barge was towed to a city landing, and the crates and bricks were again picked up and deposited directly on the material cars, each

car carrying 4,000 bricks. The bricks were finally dumped on the work within reach of the bricklayers. This method saved much time and expense in avoiding rehandling, and materially reduced the percentage of breakage.

CHAPTER X

SOME DATA UPON THE COST OF TUNNELING

Cost of hand-drilling in shaft-sinking—Cost of power-drilling in shaft-work—Cost of drifting and cross-cutting—Hand-work in tunnel driving—Diamond-drill work—Cost of square-set mine timbering—Cost of mine-hauling by compressed air—Cost of concrete tunnel-lining—Water-hauling *vs.* pumping in mines—Cost of driving a mine-heading—Cost of tunnel-driving and steam-shovel work.

While the probable cost of performing work is of the utmost importance to the bidder upon public works, for reasons easily guessed at, reliable data as to this cost is a valuable asset to the individual contractor, and, as a rule, he is not willing to publish it for the benefit of others. So many varying factors also enter into this cost that experience on one piece of work is not always a safe guide for the cost of other and seemingly similar work. But, from returns of cost carefully made by engineers, a few cases have been here selected, chiefly for the purpose of showing how such records should be kept.

Hand-drilling in Shaft Sinking.—The following detailed record of shaft sinking at the Golden Eagle Mine, Lassen Co., Cal., is given by Mr. E. H. Benjamin, M. Am. Inst. M. E. This shaft was commenced at the 400-foot level, and was sunk 150 feet below that point. The rock was hard andesite, with no water. The shaft was 7 x 12 feet in the clear; timbered by 10 x 10-inch sawed timbers, plates and center-braces dovetailed in, and center and corner posts gained in. The sets were 5 feet apart c. to c., filled and lagged with 12 x 12-inch lining set 3 feet apart.

The work was completed in forty-seven 8-hour shifts, working three shifts a day with three men on a shift. This makes an average of 3.2 feet per shift, hoisting by bucket 20 tons of material per shift, besides timbering.

For each round 18 holes were drilled; each hole $3\frac{1}{2}$ to 4 feet deep, using $\frac{3}{4}$-inch steel; No. 2 Giant powder was used for blasting; and the ground drilled hard, but broke well. Mr. Benjamin says that he does not know of a better record for hand-drilling in a shaft.

This detailed record is useful for purposes of comparison, and as showing how complete a record of this kind can be made.

DETAILED RECORD OF SINKING 150 FEET OF SHAFT AT THE GOLDEN EAGLE MINE, LASSEN COUNTY, CAL., 1902.

Detail.	*Shifts.*	*Wages, or Price.*	*Totals.*	*Cost per ft.*
Miners (9)	423	\$3.00 per shift.	\$1,269.00	\$8.460
Topmen (2)	94	2.50 "	235.00	1.566
Engineers (2)	94	3.00 "	282.00	1.880
Blacksmith (1)	47	3.50 "	164.50	1.096
Foreman (1)	47	\$100.00 per month.	172.30	1.149
Total labor	705		\$2,122.80	\$14.151
		QUANTITY.		
Timber—10,976 feet B. M.		\$13.00 per M.	\$142.69	\$0.951
Lagging—2,250 feet B. M.		0.035 per piece	88.20	.588
Lining—2,270 feet B. M.		14.00 per M.	31.78	.212
Cord wood, block G—5 cords		3.00 per cord	15.00	.100
Wedges—3,000		0.01 per piece	30.00	.200
Total timber			\$307.67	\$2.051
Wood, Fuel—25 cords		\$3.00 per cord	\$75.00	\$0.500
Oil and incidentals			15.00	.100
Total power cost			\$90.00	\$0.600
Coal oil	6 cases	\$4.15 per case	\$44.90	\$0.166
Candles	6 cases	6.40 per case	38.40	.256
Total illumination			\$63.30	\$0.422
Powder	600 lbs.	\$0.14 per lb.	\$84.00	\$0.560
Fuse	2,500 ft.	3.70 per M.	9.25	.061
Caps	550	6.25 per M.	3.44	.023
Total explosives			\$96.69	\$0.644
Total cost of 150 feet of shaft............			\$2,680.46	\$17.868

Power Drilling in Shaft Sinking.—Mr. E. C. Voorheis, Superintendent of the Lincoln Gold Mine Development Company, Amador Co., Cal., gives the following data in power drilling in shaft work, in 1902.

The Lincoln shaft was sunk from the 1,260-foot level to the 2,000-foot level, a depth of 740 feet. The ground was greenstone and hard, black slate, and the size of the excavation was 8 x 17 feet. The men worked in 8-hour shifts. The drilling was done by means of the "Baby" giant drill; the average depth of each hole in the shaft being 6 feet. Hercules powder, 40% nitroglycerine, was employed; and crude oil, at $1.50 per barrel of 42 gallons, was used for steaming. To sink the shaft 3,864 blasting holes were required, or 5.2 per foot of shaft.

During the sinking of the shaft 60,025 tons of water were hoisted; adding to this 9,456 tons of waste makes a total of 69,481 tons hoisted to the surface.

The following table gives the labor cost of sinking the shaft and putting in the timbers:

COST OF SINKING 740 FEET OF SHAFT.

Quantity.	*Class.*	*Wages, or Item Cost.*	*Total Cost.*	*Cost per ft. of Shaft.*
2,956 days	Labor	$2.75 per 8 hours	$7,129.00	
350 days	Day foreman	4.00 per 8 hours	1,400.00	
282 days	Night foreman	3.25 per 8 hours	916.50	
Total labor cost, sinking and timbering........			$9,445.50	$12.76
12,450 lbs.	Hercules powder (16.8 lbs. per ft. shaft)		1,307.25	1.76
35,800 ft.	Fuse		125.30	.17
46 boxes	Lion caps		46.00	.06
2,400 lbs.	Candles		288.00	.39
148 sets	Timbers	207,200 ft. at $18 per M	3,729.60	5.04
Total cost labor, lumber, powder, etc.......			$14,941.65	$20.18
Total labor engineers, blacksmiths, framers, etc.			6,224.00	8.41
Total cost fuel			5,893.50	7.96
Total cost, all expenses except office.......			$27,059.15	$36.56

Drifting and Cross-cutting.—From this same shaft a cross-cut was extended 642 feet, passing through 40 to 60 feet of black slate, with considerable water; and then two drifts were driven, aggregating 483 feet in length. This work was done with the "Baby" giant, and the average depth of each drill hole was 5 feet. The following table of cost was furnished by Mr. Voorheis:

COST OF RUNNING 1,125 FEET OF DRIFTS AND CROSS-CUTS.

Quantity.	*Class.*	*Wages, or Item Cost.*	*Total Cost.*	*Cost Per Ft.*
1,428 days	Labor	Miners, \$2.75; car men, \$2.50	\$3,772.50	
168 days	Day foreman	\$4.00 per 10-hour day	672.00	
134 days	Night foreman	3.25 per 10-hour day	435.50	
	Total labor cost		\$4,880.00	\$4.153
11,150 lbs.	Powder		1,226.50	1.043
26,500 ft.	Fuse		79.50	.068
35 boxes	Lion caps		35.00	.030
800 lbs.	Candles		96.00	.082
	Total cost		\$6,317.00	\$5.376

3,258 holes drilled, or 2.77 per foot; using average of 3.42 pounds of powder for each blasting hole.

Hand Work in Tunnel-driving.—The following cost data refer to a short tunnel on the W. Va. & P. R. R., driven in 1891. The tunnel was only 624 feet long, and was driven through a soft blue-clay shale, showing little stratification and practically dry. The tunnel had a span of 23 feet, was 13 feet from the floor to springing line, and the arch was a full center of 11½ feet radius. The heading area was 208 square feet; bench area, 299 square feet, or 507 square feet in all.

The work was done entirely by hand, with the following force: On heading, 1 foreman, 8 miners, 6 muckers, and one boy; on bench, 1 foreman, 8 miners, 10 muckers and one boy. Common laborers were paid \$1.45 per day, and miners received \$1.75 per day of ten hours.

In the heading three sets of holes were drilled, each set consisting of 4 holes about 4 feet deep. Each hole was loaded with from 4 to 6½-pound sticks of dynamite, and an average advance of 2½ feet was made in each blast. A derrick-car was used in handling the muck, and also for handling the timbers, lagging and packing.

The bench was taken down in 4-foot lifts, two half-depth blasts being made for each hole. Each blast consisted of 4 holes, with 10 sticks of dynamite to an outside hole and 15 sticks to the center hole. The bench-progress per shift was about 2½ feet.

The work was done by contract at the following cost to the railway company:

11,726 cubic yards excavation at $2.85	$33,419
742 cubic yards packing at $1.75	1,298
256 cubic yards fallen rock at $1.25	320
303,000 ft. B. M. timbering at $30.00	9,090
Total cost of 624 lin. feet tunnel	$44 127
Cost per lin. foot	$70.70

Cost of Driving Heading.—In 1899 the cost of driving a 7 x 8-foot heading in the Melones Mine, Calaveras Co., Cal., is given as follows by W. C. Ralston, M.E.:

This heading, or adit, was 2,608 feet long, with a grade of 3 inches per 100 feet. The drilling was done by three Ingersoll Eclipse drills, run by an Ingersoll-Sargent Class B compressor; the latter was operated by a 5-foot Pelton wheel under a head of 470 feet. The rock was diabase, brown slate and talc schists, requiring timbering on some lengths.

The working force of 29 men was divided into three 8-hour shifts of 7 men each. No. 2 40% Hercules powder was used throughout; and after each blast water, under 200-foot head, was freely used in condensing fumes and cooling the air. After eight and a half months of almost continuous use the total cost of repairs and extras for the compressor amounted to $21.32. The total cost of extra parts for the three drills was $91.65.

ACTUAL COST (EXCLUSIVE OF MANAGEMENT) OF 2,608.5 FEET OF TUNNEL AND DRIFTS, 7 x 8 FEET.

	Totals.	*Cost per Lin. Ft.*
Labor, including timbering	$19,501.46	$7.47
2,000 lbs. powder, No. 1, at 16.6 cts		
25,550 lbs. powder, No. 2, at 11.9 cts	3,405.65	1.30
75,000 ft. fuse, at 51.7 cts		
200 boxes caps, at 60 cts	500.20	.19
333½ cords wood, at $5.00	1,667.50	.63
40 ins. water and tender, at 15 cts	828.50	.32
11,591 lbs. coal, at $15 per ton and freight	179.43	.06
8,466 ft. timbering, at $20 per M	169.32	.06
3,040 lbs. candles, at 7½ cts	262.04	.10
21,555 lbs. steel rails, 1¼ to 2¾ cts	567.62	.22
Air pipe, 11 in., at 18 and 30 cts		
Air pipe, 3 in., at 22 cts		
Water pipe, 2 in., at 11¼ cts	1,042.45	.45
Hay, 1½ cts.; barley, .019 cts	267.16	.10
Steel, drill parts, oil, tools, etc	316.92	.12
Total	$28,708.25	
Actual cost per lin. ft		$11.02

The air and water pipe were in large part reused, hence comparatively small cost per lin. foot.

Tunnel Work on Ohio Residency, Pittsburg, Carnegie & Western R. R.*—This road is characterized by exceedingly heavy work in grading; and construction was still in progress in 1904. The double-track tunnel section is shown in Fig. 100. The usual method of attack adopted was to drive, at the same time, two 7 x 8-foot headings, the floor of the headings being about 12½ feet above grade. As these headings advance, the material between them is blasted out and the arch area cleared through from portal to portal. The 12½-foot bench is then removed. Two steam drills are operated in each heading, without interference. The excavated material is run out on small dump cars, and is dumped into a chute that leads to cars on the grade below.

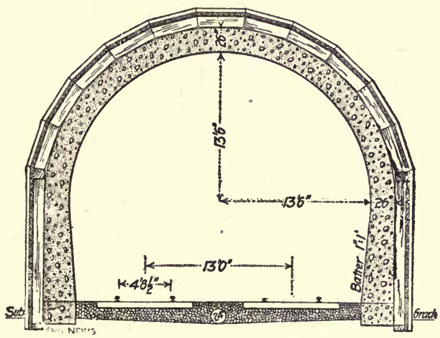


FIG. 100.—P. C. & W. R. R. Standard Tunnel Section.

The cost of driving by hand a 7 x 8-foot heading in sandstone is given as follows:

Labor, per shift	$18.20
Explosives	3.84
Repairs	.90
Light	.32
Total	$23.26

As each shift removed 6.2 cubic yards of heading, the cost was $3.75 per cubic yard.

**Engineering News*, May 21, 1903.

In another sandstone tunnel where power drills were used, the cost of driving 100 feet of a full-sized heading, running 15 cubic yards to the lineal foot, was as follows, per lineal foot of heading:

Labor	$2,527.45
2,000 lbs. dynamite, 40 per cent., at 12 cts	260.00
470 gals. kerosene oil, at 12 cts	56.40
1,875 gals. gasolene, at 12 cts	225.00
3,000 bushels coal, for compressor, at 9 cts	270.00
Machine and lubricating oil	62.50
Blacksmithing	150.00
41,649 ft. B. M. timber. at $23	957.93
Total cost 100 lin. ft	$4,509.28
Cost per lin. ft. including timber	$45.09
Cost per cubic yard, including timber	3.06

The timber was in rings of 12 x 12-inch stuff, 4 feet c. to c., lagged with 4-inch plank. This timbering is shown in Fig. 100. The ribs are usually spaced 3 feet c. to c.; though this was made 2 feet in soft ground and 4 feet in hard ground. The tunnel timbering was Georgia pine, and in one tunnel the cost was as follows:

	Cost per 1,000 *ft. B.M.*
Georgia pine, f. o. b. cars	$23.60
Hauling 6 miles	3.00
Cost of framing	5.00
Cost of erecting and bracing	3.00
Total cost in place	$34.60

To put in the packing over the lagging cost, in some cases, 80 cents per cubic yard. The carpenters who did the framing received $3.00 per 10-hour day, and the laborers who did the erecting received $1.50 for a similar day. In this case the framing and erecting cost was excessive, owing to the improper division of labor and doubling of "bosses."

Steam Shovel Work.—As shovel work may be advantageously used in the approaches to tunnels, some late notes upon the cost of work of this type are here given from experience on the Ohio Residency, Pittsburg, Carnegie & Western R. R.

With a 35-ton Vulcan traction shovel, with 1 cubic yard dipper, 11 minutes were consumed in loading 6 dump cars of

3 cubic yards nominal capacity each. To haul this train 800 feet to the dump and return, by a contractor's locomotive, required 6 minutes. Dumping one car at a time through a trestle took 3 men 3 minutes for the 6 cars.

The force employed at the shovel was: 1 boss, 1 craneman, 1 engineer on shovel, 1 fireman, 1 engineer on locomotive, 1 brakeman on train, 1 engine-driver on water-supply pump, 3 pitmen, 6 drillers, 1 blacksmith and 2 dumpmen.

This crew averaged 500 cubic yards of material excavated in a 10-hour day, the material being mostly soft shale, with a face 10 to 15 feet high. Though the shovel is apparently standing idle one-third the time, there is not so much lost time as appears. During the absence of the cars the shovel is moved forward, requiring about 3 minutes to move 4 feet and to block up.

Concrete Tunnel Lining.—In 1903 a double-track tunnel 275 feet long, and near Peekskill on the New York Central Railway, was driven and lined with concrete, and the following statement of the cost is made by George W. Lee, M. Am. Soc. C. E., engineer for the contractor.

The tunnel section (Fig. 99) was enlarged from 6 inches to 3 feet outside the concrete section, the rock being the usual rock of the Hudson River valley. As soon as the foundation trenches had been excavated and concreted, platforms 25 feet square were erected at each end of the tunnel and at the level of the springing line of the arch. Near each platform a stiff-leg derrick with a 40-foot boom was then set up, between the material track and the mixing platforms, to handle the skips. This material track ran under the platform and through the tunnel, and a turnout was laid beyond each portal for switching purposes. Steam was furnished to the hoisting engines by a 60 h.-p. boiler on wheels.

The bench-wall forms were made in 12-foot sections, with plates and sills of 4 x 6 inches, and studs of 4 x 4-inch hemlock, spaced 3 feet c. to c. The sheathing was 2-inch dressed and matched spruce. Four of these forms were set in place on each foundation at the center of the tunnel length; and wheel-

barrow runways were laid on bents leading to both mixing platforms. These bench walls were not carried back to the rock; back forms of 1-inch hemlock were used, and the space behind the walls was filled with spawls, to allow the considerable seepage from the rock to collect and run out at the "weep-holes" provided in every 15 feet of the bottom part of the walls.

While the concrete was being filled into these forms, other sections were being set up at each end of this central part. The

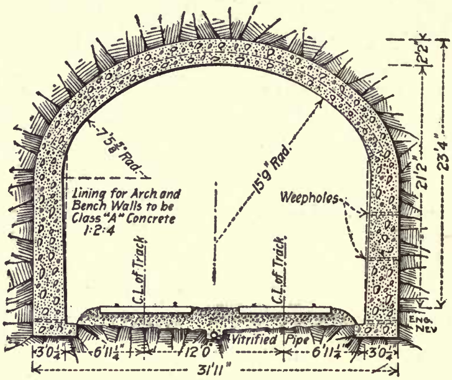


FIG. 99.—Peekskill Tunnel: Concrete Lining.

forms for the bench walls were removed in 24 hours after the concrete had been laid, and the surface was rubbed smooth with wooden floats. The bench walls terminated in sandstone portals.

Arch forms were then erected for a distance of 96 feet in the center of the tunnel, and the lagging was laid in 12-foot sections, at first extending only 3 feet above the springing line. Runways were laid over the lower chords of the ribs, the latter being spaced 4 feet c. to c. On the upper portion of the ring the concrete was first shoveled on a platform laid about 2 feet below the crown, and then passed in onto the lagging, which was here in 4-foot lengths. The arch section was waterproofed by six layers of tar paper, laid in hot tar, and the space above the arch was filled in with spawls.

The foundations, bench walls and arch were made of 1 part

cement, 2 parts sand, and 4 parts of crusher-run stone, of a size passing through a 1-inch ring. The quantities were: Foundations, 200 cubic yards; bench walls, 692 cubic yards; arch-ring, 932 cubic yards.

The total cost of the concrete work is given as follows:—

Cement, at $1.63	$5,755.50
Sand, at 75 cts	662.94
Crushed stone, at 80 cts	1,303.20
Lumber, total	1,497.71
Coal	118.73
Oil	16.12
Nails, spikes, etc	224.39
Tools	181.10
Freight on cement, stone, etc	3,089.86
Labor, including superintendent, foreman, etc	8,036.31
	$20,885.76

Average cost of concrete $10.72 per cubic yard.

Water Hoisting vs. Pumping in Mines.—An interesting paper on "Methods and Cost of Water Hoisting in the Pennsylvania Anthracite Region" was read before the American Institute of Mining Engineers by R. V. Norris, M. Am. Inst. M. E. This paper is very fully illustrated, and those interested are advised to read the original paper in the Proceedings of the Society, or its reprint in *Engineering News* of April 9, 1903. Some abstracts from the paper are here given, showing the general system and the results.

The removal of mine water by hoisting in tanks instead of pumping is rapidly coming into favor in the anthracite region of Pennsylvania, about fourteen large collieries being so equipped. Some of the shafts so cleared are 1,500 feet deep.

The hoisting tanks are cylindrical or semi-cylindrical, taking in water through chock-valves at the bottom and discharging in various ways, usually automatically. These tanks were first attached to the bottom of the regular shaft carriages; but the objection to this was the limiting of their use to the night shift, with a corresponding loss in capacity. The present practice is to locate these tanks in a special water compartment, permitting constant service, whether in a vertical or inclined shaft.

Mr. Norris gives a table of capacity, cost, etc., for two of these plants, as follows:

WATER HOIST.

	Wm. Penn Mine.	*Lyttle Mine.*
Depth of shaft	953 feet.	1,500 feet.
Capacity of tanks	1,440 gals.	2,600 gals.
Size of engines	32 x 48 ins.	36 x 60 ins.
Size of drums	Straight 12 ft. diam.	Cone 10 to 16 ft.
Capacity of hoist in 24 hours	2,100,000 gals.	3,750,000 gals.
Best record, 24 hours	2,291,040 gals.	3,772,600 gals.

COST, SHAFT AND HOIST.

Sinking and timbering	$20,673.81	$22,641.63
Head frame	4,224.13	3,540.58
Water hoist, engines and house	15,583.64	29,653.17
Tanks and ropes	2,393.23	3,899.65
Steam line	3,726.12	16,091.76
	$46,600.93	$80,777.96
Cost without shaft & steam plant.	$22,201.00	$37,093.40

At these plants Mr. Norris summarizes the operating cost of hoisting water by this method as follows, for the time noted:

	Fidler Mine, 3 years.	*Wm. Penn Mine, 37 days.*	*Lyttle Mine, 1 month.*
Depth of shaft, feet	960	953	1,500
Water hoisted, gals	918,501,200	112,468,080	236,906,000
Average height hoisted, feet	960	727.8	740.6
Cost of labor, supplies and repairs per 1,000 gals	$0.0114	$0.0088	$0.0071
Cost of steam per 1,000 gals	0.0192	0.0146	0.0148
Total cost per 1,000 gals	$0.0306	$0.0234	$0.0219

Estimating on the above data, the author places the cost of hoisting water, per 1,000 gallons lifted 1,000 feet vertically, at $0.032, $0.029 and $0.028 respectively. As compared with this he finds that the average cost of pumping water in the collieries of the Lykens Valley Coal Company is $0.0533 and $0.0390 per 1,000 gallons pumped 1,000 feet vertically.

Aside from any actual saving in operating cost, Mr. Norris claims that there are other decided advantages in the hoisting plan. (1) Simplicity of construction; (2) all the operating plant is on the surface, with a resulting low cost for repairs; (3) there is an almost total absence of slip; (4) the operating plant cannot be flooded.

An automatic electric water-hoist is used at one of the anthracite mines of the Delaware, Lackawanna and Western

Railroad. This hoist lifts 4,000 gallons of water per minute through a height of 550 feet. Mr. H. M. Warren, the electrical engineer of the company, specified an 800 horse-power induction motor to drive the hoist, running continuously in one direction, fitted with reversing clutches for driving the hoisting drum. The motor drives a pair of bevel-gears by means of a single bevel pinion; and the bevel-gear shaft carries a pinion which engages the main-gear on the drum-shaft. The two drums are of the cylindro-conical type, 16 feet and 10 feet in diameter. A steel head-frame, 93 feet high, carries two steel two-inch cables terminating in two steel buckets, each 6 feet in diameter and 19 feet 6 inches long; each bucket holding 17 tons of water. These buckets have bottom lift-gates which open automatically when the buckets reach the top and discharge the water through two lateral spouts into concrete basins built on either side of the shaft. The hoist makes a complete round trip in 1 minute 50 seconds, including a stop at either end of the travel long enough to let the upper bucket empty.

Cost of Square-set Mine Timbering.—In 1902 Mr. Bernard Macdonald presented to the Canadian Mining Institute a paper on "Mine Timbering by the Square-set System at Rossland, B. C." From this the following data are taken relating to cost:

The square-set is a rectangular skeleton framework of posts, sills, girts, diagonal braces and caps, all of comparatively short lengths and mortised together. Round, peeled, seasoned logs, or sawed timber, 8 to 10 inches in diameter, may be employed; though in the Rossland mine 16-inch round sticks, 16 feet 6 inches long, were also used. A square-set, including one post, one cap, and a girt or brace, requires 18½ lineal feet of logs, which, at 8 cents per foot in this case, cost $1.50 a set at the framing shed. The cost of framing is about $0.55 per set, framed by hand labor by carpenters receiving $3.50 for nine hours' work. The detail of this cost is:

	For material.	*For labor.*
One post	$0.65	$0.167
One cap	.43	.219
One girt	.40	.187
Total	$1.48	$0.573

The cost per set in place is:

Material	$1.48
Labor in framing	.57
Lowering into mine, about	.10
Delivering at place, about	.10
Labor erecting	1.50
Wedges, nails, etc.	.10
Sill floor, averaged over 11 sets	.15
Total per set, about	$4.00

Segregating the labor items, we find that one set of 18½ lineal feet of timber costs $2.27, or about 12 cents per lineal foot. If the timbers were 12 x 12 inches the labor cost would be about $10 per 1,000 feet, board measure, which is not excessive, considering the high rate of wages.

Mr. Macdonald says that the average space to be excavated for each set is 5.3 feet wide, 5 feet long, and 9 feet high, or 240 cubic feet. Since the Rossland ore yields 200 pounds per cubic foot in place, the cost of timbering amounts to 17 cents per ton of ore mined.

Mine Hauling by Compressed Air.—Mr. Richard Hirsch, in a paper upon this subject read before the Engineers' Society of Western Pennsylvania, gives some data upon the cost of hauling in mines by compressed air locomotives.

The 30 mules formerly used were replaced by 2 compressed-air locomotives, with 7 x 14-inch cylinders; tank capacity, 130 cubic feet; tank pressure, 500 pounds per square inch. They were built by the H. K. Porter Company, of Pittsburg. Each locomotive weighed 16,000 pounds.

In 1897 this plant was operated a total of 197 days in Colliery No. 6 of the Susquehanna Coal Company, at Lyon, Pa. The contrasted cost of operating with locomotives and mules is summarized below:

Total cost of plant, except steam boilers, cars and track	$15,156.00
Operating expenses, including all labor, fuel, supplies, repairs, etc.	2,202.78
Fixed charges, including interest, depreciation and renewals	1,776.60
Cost of mules required for same work	4,052.48
Cost of operation by mules, including labor, supplies, interest, depreciation, etc., for 179 days	11,328.63
Cost of operation by compressed air	3,979.38
Saving in cost of operation	$7,349.25

The daily average work of these two motors for 197 days was 1,185 net ton-miles; or, the cost of hauling per net-ton mile was 1.9 cents. The corresponding cost by mule haulage was 5.34 cents. For 300 working days the contrast would have been still greater.

Cost of Diamond-drill Exploration in South Africa.—The 1901 report of the Commissioner of Mines for Natal Colony, South Africa, gives some interesting data as to the cost of exploring by the diamond drill in that country.

The carbons used were inferior Brazilian diamonds, costing $50 per carat, and Kimberly stones at $15 per carat. The cost of the carbons per foot of hole drilled was 20 cents for a 2½-inch hole in the softer rock, and $1.35 for a 3-inch hole in quartzite. Both hand-driven and steam drills were used.

With hand-driven drills, the cost and progress made is shown by the following table:

Hole.	*Kind of rock.*	*Diameter, inches.*	*Depth, feet.*	*Shifts, 10 hours.*	*Feet, per shift.*	*Total cost.*	*Cost per foot.*	*Feet of soil.*
1.	Sandstone.	2	78	9	8.7	$145.54	$1.86	2
2.	Sandstone.	2	80	9	8.9	142.15	2.02	10
3.	Shale.	2	28	3	9.5	48.95	1.70	5
4.	Sandstone.	2	161	14½	11.1	464.55	2.90	12
5.	Sandstone.	2	341	35	9.7	406.35	1.20	0
6.	Whinstone.	2	369	93½	—	2,146.00	5.85	0
7.	Sandstone.	3	81	7	11.6	197.65	2.44	6
8.	Shale.	3	116	15½	7.8	240.60	2.10	1

For drills driven by steam power, the similar record for another set of holes is as follows:

Hole.	*Rock.*	*Diameter, inches.*	*Depth, feet.*	*Shifts, 10 hours.*	*Feet per shift.*	*Total cost.*	*Cost per foot.*	*Feet of soil.*
1.	Shale.	6	170	24	7.1	$401.70	$2.34	2
2.	Shale.	3	96	5½	17.5	267.40	2.79	30
3.	305 ft. Shale. 146 ft. Whinst'e.	3	615	77½	7.9	1,851.25	3.40	4
4.	Sandstone.	2½	85	2¼	18.9	145.35	1.70	—
5.	Sandstone.	2½	176	3½	25.4	165.40	0.92	9
6.	Sandstone.	2½	147	2⅛	34.7	154.50	1.05	9
7.	Sandstone.	2½	201	5½	36.5	153.00	0.76	15
8.	Sandstone.	6	154	17½	5.8	1,181.70	7.55	13

In both tables only the actual boring shifts are noted; about 20% of the actual time consumed and paid for in total cost was taken up by Sundays and holidays. On a steam drill the crew numbered 1 white man and 5 to 6 natives, and the wages paid were evidently very low, amounting to about $4.50 per drill crew, including rations. On hand-drills 1 white man and 8 natives were employed.

Cost of Diamond-drill Work in Montana.—Mr. A. P. Davis, Principal Engineer U. S. Geological Survey, gives the following data on diamond-drill boring in connection with the irrigation surveys in Montana.*

Six holes were bored to an aggregate depth of 340 feet, a hard, somewhat coarse and seamy granite being generally found about 40 to 50 feet below the surface of the rivers investigated. The total expenditure for the gang of 4 to 5 men was $523 per month, including salaries ($330), subsistence, interest at 3% on machinery costing $2,800, wear and loss of carbons ($30), and fuel.

At 26 working days (of 10 hours each) to a month, it cost $20.12 per working day to run the drill. It took 38½ working days to put down the 6 holes, at a total cost of $769.60. As the combined depth of the holes was 340 feet, this averages $2.26 per foot of holes drilled. But of this 340 feet only 79 feet was diamond-drilling, and 55 feet was water.

Engineering News, April 30, 1903.

CHAPTER XI

THE VENTILATION OF TUNNELS

The principles of artificial ventilation—The Saccardo system—Ventilation methods on the Boston Subway—The East Boston tunnel—The Baltimore & Potomac tunnel—The Paris-Orleans Railway—The Pennsylvania Avenue Subway in Philadelphia—The Simplon tunnel.

The mechanical ventilation of a tunnel, whether in process of construction or in actual operation, is one of the troublesome problems presented to the engineer. In the one case, the fumes arising from the blasting charges have to be removed as speedily as possible from the headings, so as to avoid loss of time in clearing away the broken rock; and, in the other case, the air vitiated by the gases arising from the combustion of coal has to be replaced by fresh air.

In tunnel construction the heading is usually cleared by leading a tight but light pipe as near to the heading as possible, and then sucking or blowing out the foul air by a fan of suitable dimensions, located at the portal or on top of a shaft. In ordinary operations, the working conditions are such that more elaborate appliances are not economical.

In a railway tunnel, with a dense traffic through it, ventilation is a more serious problem. In certain cases, where the ratio of the necessary interval between trains to the velocity of the natural current through the tunnel is not too great, natural ventilation may clear the tunnel of foul air. The natural current here referred to is dependent upon the difference in temperature inside the tunnel and outside, and upon the difference in barometric pressure between the two portals—in other words, their relative elevation above sea level. In small tunnels these two causes are not appreciably operative; but

wind action and the mechanical effect of the train passing through a tube may effect the ventilation.

Artificial ventilation is now the rule wherever the train intervals are short; and the principle generally adopted is that of exhausting the vitiated air at a point midway of a tunnel, or tunnel section, and drawing in fresh air at the ends of the section.

In a paper upon this subject, presented to the Institution of Civil Engineers by Francis Fox, M. Inst. C. E., the author says that he has ascertained by experiment that so long as the amount of carbon dioxide in the air does not exceed 20 parts in 10,000, the air in a railway tunnel is satisfactory.

Mr. Fox goes on to say that, having ascertained the consumption of coal by a locomotive in its passage through a tunnel, and allowing 29 cubic feet of poisonous gases for each pound of coal consumed, the volume of fresh air required to maintain the tunnel at the above standard can be ascertained as follows:

The number of pounds of fuel consumed per mile, multiplied by 29, multiplied by 500, and divided by the number of minutes' interval between trains, will give the cubic feet of air which must be introduced per minute into the tunnel. Assuming as an illustration a tunnel one mile long, consumption of fuel 32 pounds per mile, and one train passing through the tunnel in each direction every five minutes, the volume of fresh air required per minute will be:

$$\frac{32 \text{ lbs.} \times 29 \text{ cu. ft.} \times 500}{2\frac{1}{2} \text{ min.}} = 185{,}600 \text{ cu. ft.}$$

This is the basic principle of the ventilation of the Mersey and Severn tunnels; and the ventilation was satisfactory until the traffic exceeded the capacity of the ventilating plant originally put in. In the Mersey tunnel the system of electric traction was adopted in 1902.

Experience in the operation of city subways by electric power tends to prove that ventilating appliances, especially in summer,

are almost as necessary as in the older tunnels. In this case, however, it is a question of reducing undue heat rather than that of the removal of gases resulting from the combustion of coal.

In these electrically operated underground tunnels we have a great number of motors constantly consuming a very large quantity of electric power. This power is almost wholly expended in overcoming friction in the journals, in the wheels and rails, in brake-shoes, and in the air at the head and sides of trains; and even the force used to overcome the inertia of the trains is expended again in friction when the brakes are set to retard the trains; and the electricity lost in transmission through the third rail is a frictional loss. This expended power is not lost; it is converted into heat, and this addition to normal temperature must be reckoned with by the engineer designing subways.

Actual experiments made in the New York subways in the summer of 1905 show that the temperature in the subway and in the cars is from 4° to 6° higher than the thermometric readings taken at the same time at the street surface above. These New York subways exceed any previously operated subway in the traffic density, weight of trains, size of motors, and power expended. And, while complaints have been made of bad ventilation in some of the earlier electric-motor operated tunnels, it has remained for the New York subway to demonstrate that the heating effect of electric power upon the air of the subway must be considered and provided for in the design of such tunnels.

In designing the Boston subway, also operated by electricity, the engineers provided an efficient ventilation plant, described later in this chapter. But while this plant was originally employed to regulate the temperature within the tunnel and to prevent it from falling to a point too much below the normal temperature, it has certainly regulated as well the surplus heat in that tunnel resulting from the expenditure of electric power. This tunnel is cool in summer, though it cannot compare in traffic and in motor power with the New York subways.

Saccardo System of Ventilation.—The Pracchia tunnel is one of 52 single-track tunnels on the railway between Florence and Bologna, in Italy. The gradients are about 1 in 40, and the traffic requires the use of heavy locomotives. The Pracchia tunnel is 9,000 feet long; under any condition of wind the air within is bad, and with a wind blowing in at the lower end the state of affairs is almost insupportable.

Marco Saccardo, a prominent Italian engineer, applied his system of ventilation to this tunnel with remarkable results. He availed himself of the annular space between the interior of the tunnel and the extreme cross-section of the carriage. And, upon the principle of the injector, he uses a fan to blow a large volume of air into the mouth of the tunnel; this induces a

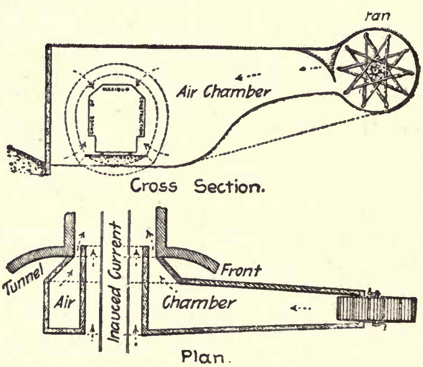


Fig. 101.—The Saccardo System of Tunnel Ventilation.

strong inward current through the central opening used by the train.

As shown in Fig. 101, Saccardo extended the tunnel by a structure of brick, about 20 feet long; the inside of the central opening representing the line of maximum train cross-section. This structure extended about 3 feet into the tunnel, with an opening toward the tunnel through which air was forced from the air-chamber.

Francis Fox, M. Inst. C.E., measured the volume and temperature in the tunnel thus equipped, with the following result: Before starting the fan the tunnel was filled with dense smoke

from end to end; the temperature was 107° F., with 97° of moisture, or nearly complete saturation. With the fan running the temperature fell to 80°, or that of the external air; the moisture was normal; the amount of air propelled by the fan was 164,000 cubic feet per minute, with 46,000 cubic feet resulting from the induced current, making a total of 210,000 cubic feet of air per minute passing through the tunnel. The air was blown in at the upper end of the tunnel; with the object that the gases from an ascending train may be blown down the incline and out at the lower end. Mr. Fox says that the air in the tunnel was cool and fresh. But this principle could not be applied to subways, as the smoke would simply be blown to the next station, just where everything should be clear.

Boston Subway.—While this subway is operated by electric-

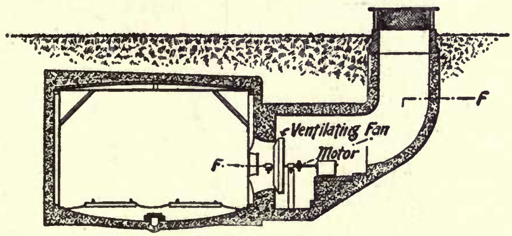


FIG. 102.—Ventilating Chamber: Boston Subway.

ity, and the removal of smoke and gases resulting from the combustion of coal need not be considered, engineers now recognize the necessity of a positive and continuous change of air in subways. This is necessary for the double purpose of maintaining the purity of the air and for regulating the moisture in the air, thus preventing the deposit of moisture and the chilling of passengers and employes. The dew-point of air of 90° F., with a relative humidity of 70%, is about 79° F. It is thus plain that with an external temperature of 90°, and a slow and uncertain movement in the air within the tunnel, this air may be readily cooled through 10° or more; it would then become saturated, cause inconvenience by drippings from the structural work, and become a positive menace to health.

For these reasons the plans for the Boston subway called for ventilating stations located at suitable points and equipped with fans driven by electric motors. These stations are placed about midway between entrances; and the fans are designed to change the air in any one section once in 15 minutes.

Fig. 102 shows the general design of one of these stations. All of the fans are of the Sturtevant cone type, and the two fans between Hollis and Eliot streets are each 7 feet in diameter and are each designed to deliver 30,000 cubic feet of air per minute, at 175 revolutions per minute; they require an expenditure of about 7 horse-power each under ordinary conditions. Each fan is provided with an electric motor directly connected to the fan-shaft by an insulated coupling, and mounted on a substantial insulating base-frame made of Georgia pine, thoroughly filled to prevent absorption of moisture.

East Boston Tunnel.—In the harbor portion of this tunnel, which is to be operated by electric cars, a complete ventilation system has been installed on the following plan: The double-track tunnel under the harbor is about 23½ feet wide at the springing line of the arch, with a cross-section of 332 square feet; while the four-track land sections have a cross-section of 707 square feet. In both land and harbor sections resort is had to direct ventilation by exhaust fans; the exhaust fans being set in chambers about midway between stations. These fans take the air from the tunnel and discharge it upward, usually through grated openings in the sidewalks. Fresh air enters at the stations and flows each way to the fans.

The harbor section is provided with a shaft at either end containing the exhaust fans, located near the surface. In the crown of the tunnel is a duct, with a cross-section of 48 square feet, this duct being made of a diaphragm 1 inch thick, constructed of expanded metal and concrete. This diaphragm is suspended to the crown of the arch by steel rods and plates also incased in concrete. Midway of the tunnel a partition divides this duct into two parts, and on each side of this partition there are 14 openings, each 4 feet long and 1 foot 5 inches wide, situated in the flat portion of the duct; and at intervals of about

550 feet there are other groups of openings, diminishing in number as they approach the fan chambers. These openings are fitted with doors that can be operated from the tunnel below. When the movement of the air in the tunnel is not effected by the wind the two groups of openings close to the middle partition are alone used.

Fresh air enters the tunnel at the portal at East Boston and through the station at Atlantic avenue on the Boston side. This fresh air from both ends passes to near the middle of the tunnel and is drawn into the openings near the middle portion by the action of the exhaust fans, and is discharged through the ventilation ducts and through the fan-shafts at either end.

It should be mentioned that the ventilating duct is curved downward for the central two-thirds of its entire span, or between the suspending rods and plates. The two side portions, between the suspenders and the arch, are flat, and in these the openings referred to are located.

Baltimore & Potomac Tunnel.—The ventilating plant here described is found in the tunnel of the Pennsylvania Railroad Company, in the city of Baltimore, built in 1892, under Joseph T. Richards, Assistant Chief Engineer Pennsylvania Railroad Company. This plant was one of the first of its type to be operated by electric power.

The plant includes a motor-house, a stack 102 feet high and 13 feet 6 inches square inside, and the conduit connecting the tunnel with the fan-chamber. The fan is a plain Davidson ventilating wheel, 15 feet in diameter, with a velocity of 658 feet per minute at the periphery. The conduit is circular, 15 feet 6 inches diameter. This plant controls 3,600 feet of tunnel measured between portals, and it is designed to change the air in the tunnel once in five minutes; this requiring a velocity of 42.6 feet per second in the air passing through the conduit connecting the tunnel and the shaft.

The power-house is located about 3,200 feet distant from the fan-chamber, and it contains a 100 horse-power boiler, a 90 horse-power engine, and an 80 horse-power Thomson-Houston dynamo. A copper cable transmits the power to the motor-

house, which contains a 45 horse-power Thomson-Houston motor, which is so connected as to run the fan at 14 revolutions per minute.

Paris-Orleans Railway.—The Paris section of this tunnel is operated by steam locomotives, as it was deemed inadvisable to change the traction system. As a result, mechanical ventilation was introduced.

The plan adopted was very similar to that used at the Mersey tunnel, as shown in Fig. 104. Just outside the haunch of the main arch a small circular conduit was built, connected with a

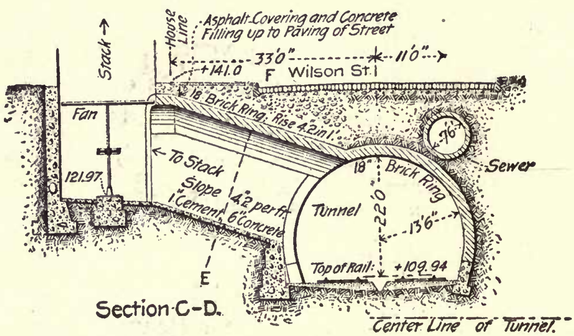


FIG. 103.—Baltimore & Potomac Tunnel: Section of Conduit Leading to Fan-chamber.

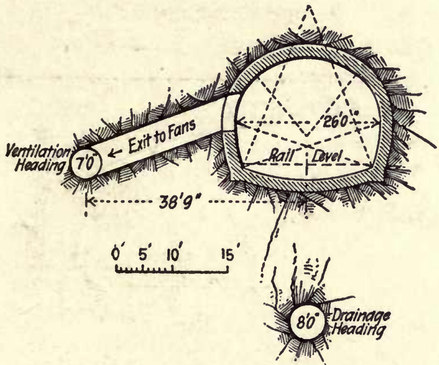
fan at the main station. This conduit connected with the tunnel at regular intervals; and fresh air was taken into the tunnel through the stations, and also through specially provided inlets in the sidewalks, covered by a small building with the sides used for advertising purposes. The system seems to work well.

Pennsylvania Avenue Subway.—This subway, about 3,000 feet long, was built by the Philadelphia & Reading Railroad Company to remove 17 dangerous grade crossings in the heart of Philadelphia. The tunnel section has the unusual dimensions of 52 feet span in the clear and it is 22 feet high. As the traffic is dense a complete system of artificial ventilation had to be provided for.

The general plan is shown in Fig. 104a, and includes two

fan stations, side exhaust conduits and fresh-air intakes. The two fan stations divide the tunnel into four almost equal sections. At each station are two 20-foot fans driven by electricity, which draw out the foul air through openings in the arch located at 150-foot intervals; these openings lead to a circular conduit of varying dimensions, draining toward the fan stations. The conduits decrease in diameter from 11 feet at the fan station to 6½ feet at the ends.

The fresh-air intakes are located on the other side of the tunnel and deliver the air at the rail-level. These intakes are



Cross Section.

FIG. 104.—Mersey Tunnel: Showing Ventilating Conduit.

located midway between the foul-air openings and, as a rule, they are placed in grass plots falling between the curb and the sidewalk.

Each fan is figured to have a capacity of 150,000 cubic feet per minute, or 600,000 cubic feet in all; as this is about one-fifth of the cubic contents of the tunnel, the air should be renewed every 5 minutes.

Ventilation of the Simplon Tunnel.—For ventilating this tunnel during and after construction a permanent ventilating plant was installed at each end of its 12.4 miles length. The plant at each end consisted of two 200 horse-power turbines running at 400 revolutions per minute and driving two fans, each 12.3 feet in diameter. The elevation of the Swiss entrance to the

tunnel is 2,250 feet above sea level, while the elevation at Iselle, at the Italian end, is 2,076 feet above the same level. The highest point of the tunnel, about midway, has an elevation of 2,310 feet above sea level.

At the Swiss end the fans were placed one above the other, close to the portal; and at the Italian end the fans were placed one behind the other. In the latter case the air passes first to a ventilator-house, and thence by a passageway to the tunnel. The ventilating plant at each end furnished 50 cu. m. of air per second at a gage pressure of 250mm. of water, when running in parallel; and 25 cu. m., at a pressure of 500 mm. of water,

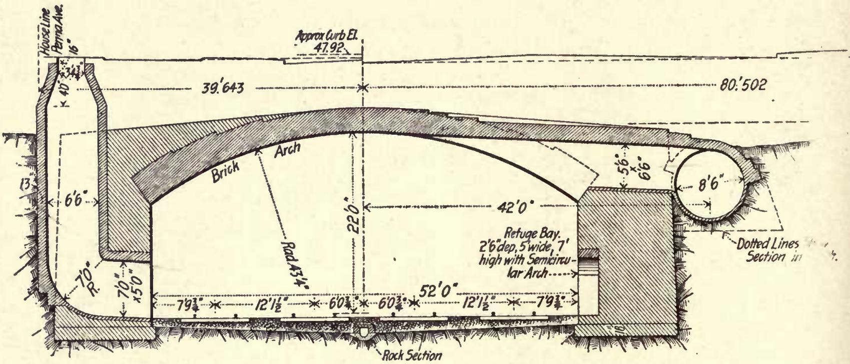


FIG. 104a.—Ventilation of the Pennsylvania Avenue Subway.

when running in series in a tunnel 10 kilos long and 8 square metres in sectional area.

It should be stated that two twin tunnels form this line, each single-track, spaced 55.76 feet apart, c. to c. These tunnels are lined throughout with masonry; and though the thickness of the lining varies, the clear width of each tunnel at the springing line is 16.43 feet. During construction only one of the tunnels was driven to its full dimensions, the other being represented by a small gallery which served for drainage, ventilation and other purposes connected with the tunnel work. At intervals of 656 feet the tunnel and this service gallery were connected by transverse galleries laid out on an angle of about 60° with the tunnel axis. The alignment of the tunnel is straight, except for a short curve at each end.

Returning to the ventilating plant, the air-passage from the ventilator-house bifurcates near its tunnel end and one fork goes to each tunnel; a door at the angle of the bifurcation closes either passage to the tunnels at will. Sailcloth curtains close the portals of the tunnel, and these are operated by hand or by electric motors. By this arrangement—and when the tunnels are completed—the air can be circulated in either tunnel as desired, the movement of the air being accomplished by compression or by aspiration; the cross-galleries between the tunnels referred to having been then sealed up.

To ventilate the workings during construction was a more complicated operation. In this case the air was forced through a branch to the service gallery, and it passed along this gallery to the most advanced cross-gallery, and then back to the portal along the main tunnel of full section. If the air were exhausted instead of being forced in, the direction of flow would be in the opposite direction. It should also be noted that all side passages are sealed up as the work advances to prevent the short-circuiting of the air-current. As installed, this ventilating plant was in excess of the needs of construction. One fan operating so as to give a gage pressure of 60mm. of water, gave one cubic foot of air per second at the working face. An increase of pressure to 100mm. of water blew out the miners' lamps. To lay the dust and freshen the air entering the fans the sides of the air passages were occasionally flooded with water.*

Before commencing this work the elevation of temperature due to the heat of the rock was estimated at 1°C. for every 44m. of advance. But, owing to different influences encountered the actual temperatures differed materially from the estimates. At the Italian side the heavy inflow of water kept the air cool for a considerable advance. But on the Swiss side the infiltration of water was small and it was a matter of some difficulty to keep the air cool enough for the men to work. The highest temperature met with up to the autumn of 1902 was 55°C., and at the eighth kilometer from the Swiss end.

*A detailed description of the plant and the methods pursued in driving the Simplon tunnel will be found in *Engineering News* for August, 1903.

To refrigerate the air, cold water was forced into the headings and then broken into spray. The 10-inch pipe carrying in the water from the Rhône, on the Swiss end, was jacketed with a $15\frac{3}{4}$-inch pipe and the annular space was filled with charcoal. In passing through 9 kilometers of this protected pipe the rise in temperature in the water was only 3°C.

CHAPTER XII

AIR-LOCKS

The general purpose of air-locks in tunnel work—Their location—The limit of human endurance under compressed air—Effect of compressed air upon the workmen—Compressed-air hospital locks—The O'Rourke air-lock—Mirabeau bridge air-lock—The Hughes air-lock—Hyde Park tunnel air-lock—Morison air-lock—Victoria bridge air-lock—Air-locks at Kiel dry-dock.

So far as tunneling is concerned, compressed air is only employed in subaqueous work, located not more than about 100 feet below the water surface. Air-locks—the essential feature of this method of tunneling—cannot, therefore, be omitted in this work, as shaft-sinking is a form of vertical tunneling; and when much water is encountered, compressed air is commonly used for its expulsion. This chapter on air-locks has been made quite general in its application.

Briefly expressed, an air-lock is a means devised by engineers for passing from the outer air to a working chamber filled with air compressed to a degree sufficient to expel and support the column of water under which the work is being conducted. As it enables the workmen to pass at will from one air-pressure to another, it is comparable to the lock of a canal employed for the purpose of transferring boats from one water level to another.

Air-locks may be applied vertically, as in sinking a vertical, cylindrical shaft or a caisson; or, they may be used horizontally, as in subaqueous tunneling where an inrush of water is to be guarded against. The latter use of air-locks is attended with danger; especially if the soil penetrated is sand or silt with a comparatively slight depth of material between the roof of the tunnel and the bed of the river. In such cases, the compressed

air may find an opening in this loose material; and a "blow-out" occurs, reducing the pressure in the tunnel so suddenly that an inflow of water may result. This accident occurred several times during the construction of the North River tunnel, through silt, and in one case many lives were lost. This contingency is often guarded against by the use of clay-bags disposed in a sufficiently broad layer on the bed of the river and immediately over the line of the tunnel. The clay-bags are better than loose clay deposited on the river bed, as the loose clay may be washed away by the current.

In horizontal tunneling, double sets of air-locks are usually provided; one set devoted exclusively to the passing out of debris and the passing in of the materials of construction, and the other is for the use of the workmen. In work of this character it is also customary to provide guard-locks to prevent the whole length of a tunnel from being flooded by reason of any accident to the main advance air-lock. These guard-locks are usually located in bulkheads of masonry built at some distance in the rear of the advance shield and lock, and thus inside the completed lining of the tunnel.

In the horizontal as well as in the vertical application of compressed air to structural purposes, by means of air-locks, the safety of the workmen demands that a proper time should be allowed in the equalization of the air-pressure in the lock; this time depending upon the position of the lock, or the working chamber, in relation to the water surface, and the consequent air-pressure necessary to expel the water.

The chief danger lies in the effect upon the human organism of a too sudden transition from a high air-pressure to the normal atmospheric pressure; though evil results may also follow from the locking-in process, if the higher pressure is too quickly admitted into the air-lock.

A series of interesting experiments were made in 1895, by Mr. Hersent, the engineer of the harbor works at Bordeaux, as to the limits of human endurance under higher pressures than those usually employed in the pneumatic process. He fitted up a test air-lock with windows, telephone, electric light, steam

coil for heating, etc. Three volunteers, two experienced workmen and one who had only been under air-pressure a few times, were subjected to pressures for about one hour at a time. The tests commenced with a pressure of about 28.4 pounds per square inch, and this pressure was increased very gradually, by about 4.27 pounds per day, to 76.8 pounds per square inch. The time for the pressure reduction was increased about 10 minutes for each 1.42 pounds in increase of pressure. All three men sustained without difficulty a pressure of 46.9 pounds, with a reduction period of 56 minutes. One man then withdrew from the test, owing to an independent cause. At 58.3 pounds pressure the man accustomed to the work felt some inconvenience; and at 65.4 pounds the man who was not accustomed to compressed air had to be withdrawn as he suffered from pain in his side, though there was no trace of paralysis. But the experienced man withstood a pressure of 71.1 pounds for one hour, and this pressure was reduced in 2 hours 25 minutes. This same man underwent the final test of a pressure of 76.8 pounds, raised in 45 minutes and continued for one hour; this pressure was then reduced to normal pressure in 3 hours 3 minutes. Mr. Hersent says that the man who endured this abnormal pressure suffered no inconvenience other than a tingling sensation, which passed away after a short time.

Mr. Hersent believed that, if certain precautions were taken, men in good health could safely withstand a pressure of 76.8 pounds per square inch for a limited time. This pressure of 76.8 pounds is equivalent to a depth of about 178 feet below the water surface and far exceeds any depth worked under compressed air. For a long time about 100 feet was considered as a maximum safe working depth, and at that depth men were not permitted to work more than an hour on one shift. So far as the writer has any knowledge, the greatest pressure actually employed in compressed-air work was 52 pounds, corresponding to a head of 120 feet, in the construction of the East River Gas Company's tunnel under the East River, at New York. There the ordinary pressure was about 45 pounds, correspond-

ing to a head of 104 feet. At the Limfjord bridge, in Denmark, men worked for some time at a depth of 113 feet.

During the earlier stage of construction of the Hudson River tunnel, in 1890, a compressed-air hospital lock was established at the New Jersey entrance for the treatment of workmen who were suffering from the effects of high air pressure. At this work the pressure, at that time, did not exceed 33 pounds per square inch, but some of the men suffered severely from partial paralysis, or "the bends," as it is termed. It was found by experience that the most effectual remedy for this attack was to send the patient back into the working chamber, and when he had recovered from the attack, to bring him out very slowly through the air-lock.

But, as the air-lock proper is constantly required for other uses, a special hospital air-lock was constructed for this purpose. This was simply a steel cylindrical shell 18 feet long and 6 feet in diameter, fitted with the proper doors, inlet and outlet pipes, etc., and provided with beds. The cylinder is divided into two halves by a center diaphragm with a door, so that after the patient has been placed under the effect of compressed air in the inner half the doctor can pass out through the other half, operated as an air-lock.

Each chamber contains two narrow beds, and beneath the floor are located steam-radiating pipes for heating the chambers. Incandescent lamps are also provided, and glass windows permit the attendant to watch the patient from the outside. Fresh air is provided by a special valve arrangement, and all valves are controlled from the outside so that an impatient workman cannot interfere with them in his desire to get out at a quicker rate than is safe. In releasing the patient from the lock, two or more hours are consumed in letting off the pressure.

A most valuable report upon the effect of compressed air upon the human system was made in 1871, by Andrew H. Smith, M.D., Surgeon to the New York Bridge Company, then sinking the foundations for what is now known as the Brooklyn Bridge, in New York. Dr. Smith made a special study of

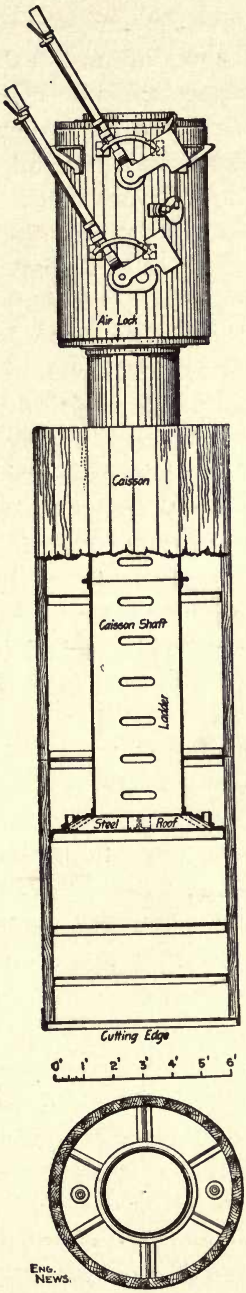


FIG. 105.—The O'Rourke Wooden Cylinder Caisson, Caisson Shaft and Air-lock.

the so-called "caisson disease," and the effects of high atmospheric pressure upon the workmen. He defines the disease and its symptoms and causes, describes his method of treatment and illustrates his deductions by a large number of actual cases. He recommends and describes a hospital air-lock very similar to that used at the Hudson River tunnel. A. Jaminent, M. D., Physician to the St. Louis Bridge, has also published a valuable report on "The Physical Effects of Compressed Air."

O'Rourke Air-lock.—The air-lock here illustrated was designed and used by John F. O'Rourke, M. Am. Soc. C.E., in sinking various foundations in New York City.

These locks were used with cylindrical wooden caissons, also designed by Mr. O'Rourke and worthy of description first. Each cylinder was 6 feet $7\frac{1}{2}$ inches outside diameter and was made up of staves cut with radial sides and having inside angle-iron hoops bolted to the staves. The staves were made of 4 x 6-inch plank, dressed to $5\frac{1}{2} \times 3\frac{1}{2}$ inches, and having 1-inch square slip tongue joints. Any two lengths of this cylinder were connected by a double angle joint. The roof of the working chamber was made by a ring-shaped diaphragm of steel plate. Attached to the wooden staves at the outer edge by a special angle-ring bolted to each stave, and to its inside edge, was bolted the bottom of the caisson working shaft, as shown in Fig. 105.

The steel caisson-shaft, 3 feet in diameter, connects the air-lock with the working chamber at the base of the wooden cylinder. This riveted cylinder is specially designed with the object of providing a shaft that has no interior projections liable to catch or obstruct the hoisting of the bucket. But as it must also be used as a "man-shaft," Mr. O'Rourke devised a ladder which fills the first-named condition of non-obstruction. In one side of the cylinder is cut a series of horizontal oblong holes, at a convenient distance apart and one above the other, so as to form a "ladder." To prevent the escape of air at these holes a continuous, trough-like cover plate is riveted outside of these holes, and far enough away from the side to allow the hand or foot to be inserted in the slots.

The air-lock (Fig. 106) is cylindrical in form, with a top and bottom opening *B* and *C*. Around the top opening is a circular inside ring *D*; this opening is closed by the oppositely

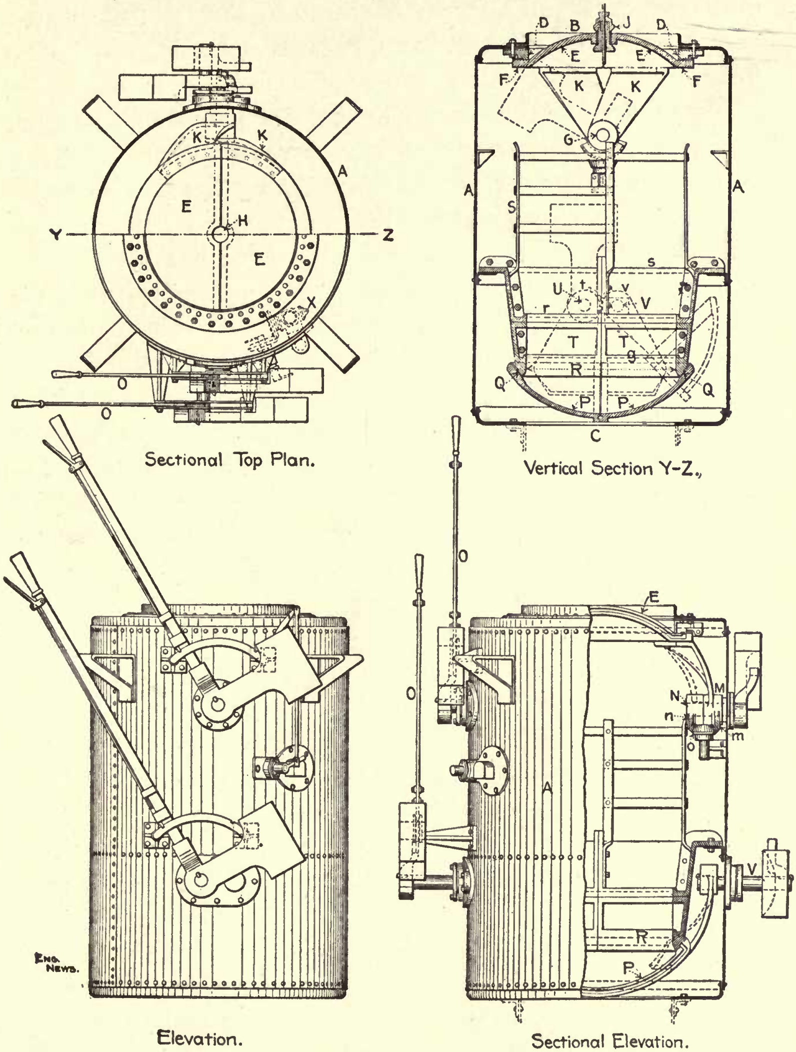


FIG. 106.—The O'Rourke Air-lock: Details.

arranged, convex, swinging gates *E*, the meeting edges being packed so as to form an air-tight joint. The outer edges of

these gates are provided with flanges *F*, which close against the ring *D*; the flanges having flap-gaskets projecting into the lock so that the air pressure forces them against *D*. Ordinarily, all the pressure on the doors *E* is taken by the shaft *G*; yet the ring *D* may be made to act as an emergency bearing to take the pressure.

The gates *E* are cut away at the center of the meeting edges, as shown at *H*, to receive and fit snugly upon the stuffing-box *J*, banded with rubber and having a hole through the center for the hoisting rope. The gates *E* are hung by the arms *K* to the common shaft *G*; one, *M*, being fixed to the shaft and the other, *N*, running loose. This arrangement by means of the bevel-gear and idler, *m n o*, allows the two doors to be moved in unison and in opposite directions. This hanging of the gates on a single center obviates the necessity of piercing the shell in more than two places, and reduces leakage. The drawings show how the shaft *G* is rotated by the levers *O*, the latter being counter-weighted so that one man can operate the lock.

The air-lock has its lower end closed by similarly oppositely arranged swinging gates *P*, with seats *Q* fitting against the ring *R*. The castings forming the ring *Q* have flanges, *q r s*, which continue the shaft-ladder already described, and are themselves continued by the ladder-like structure *S*.

Unlike the upper gates *E*, the lower gates *P* are swung by the arm *T*, from separate shafts *U* and *V*. The gate-arms are rigidly fixed to these shafts and turn with them. To secure opposite motion to the shafts, one is operated by a spur-wheel from the other, as shown at *t* and *v*, operated by the lever *O*.

The admission and discharge of air from the lock is controlled by the three-way cock *X*, operated by a lever and bevel-gear and connected with suitable piping to the air-shaft. There are no independent connections with the compressors, as usual.

To operate the lock, the bucket being at the bottom and the bottom gates *P* necessarily open, the bucket is raised up into the air-lock and the bottom gates *P* are closed behind it. The air is then discharged by the valve *X* from the lock and the top gates *E* are opened. This allows the bucket to be hoisted out

and dumped or loaded. In the return process the bucket is hoisted into the lock and the top gates are closed, care being

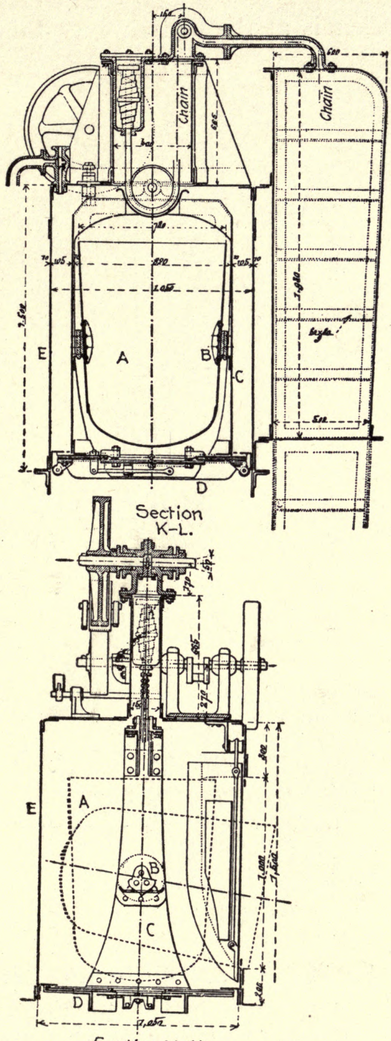


FIG. 107.—The Zschokke and Terrier Air-lock: Mirabeau Bridge, Paris. Elevation and Plan.

taken to fit the rope in the stuffing-box *J*. The air pressure being admitted, the bottom gates are opened and the bucket

descends into the working chamber. This whole operation usually takes about ten seconds and is accomplished by one man.

When the bucket is at the bottom everything is clear open

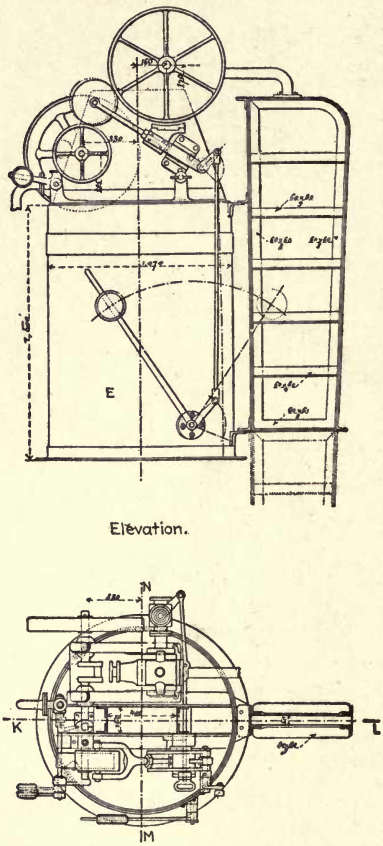


FIG. 107a.—The Zschokke and Terrier Air-lock: sections.

to the top of the air-lock, and in case of a sudden inrush of water the men can escape up the ladder and into the lock. The lock and air-shaft can be removed and used again.

Air-lock, Mirabeau Bridge, Paris.—The river piers of this bridge were founded upon metallic caissons, 33 x 92 feet in

their dimensions, sunk by compressed air to a hard chalk stratum 54 feet below the water line.

The working chamber is about $6\frac{1}{2}$ feet high and is connected with the open air by four shafts. The two middle shafts, 2.8 feet diameter, are fitted with air-locks of the ordinary type, and are used by the workmen. The two end shafts are used for removing the material; they are each 3.4 feet in diameter and terminate in the Zschokke-Terrier air-locks, shown in Figs. 107 and 107a.

These latter locks are designed for rapid operation and would be dangerous if used by the workmen, owing to the quick changes in pressure. The bucket *A* rests on two trunnions, on racks *B* attached to the frame *C*; the latter carrying at its lower end a plate *D*, which closes the bottom of the chamber *E*. This frame is suspended by a chain, one end of which is fixed to the top of the chamber and is fitted with a relieving spring. This chain passes down under a pulley fixed to the bucket frame; then over a small grooved wheel in the top of the chamber, and then runs down the shaft, as shown. The shaft of the grooved wheel last referred to extends outside the chamber, and terminates in a wheel driven by a friction wheel on a small compressed-air engine located on top of the lock. By this means the chain is raised or lowered.

When the filled bucket reaches the top of the shaft, the latter is closed by the plate *D* fitting against a rubber-faced steel-ring. A valve automatically opens which allows the compressed air to escape from the chamber; and as soon as this is done a swinging door is opened in the side of the chamber and the bucket is dumped. The door is then closed, the compressed air is let into the chamber again and the bucket descends by its own weight.

As shown on the plan, the chain runs down a special conduit of wrought iron, made air-tight.

Hughes Air-lock.—The late John Hughes, M. Inst. C.E., devised the plan here described for sinking wrought-iron cylinders for an iron pier built by him at Valparaiso, Chili, in 1873-83. The water was generally 48 feet deep, but some

of the cylinders were sunk 107 feet below the surface of water.

The wrought-iron cylinders were 11 feet 4 inches outside diameter, made in sections 8 feet long and connected by angle-iron. Each cylinder had an inner cylinder 8 feet in diameter.

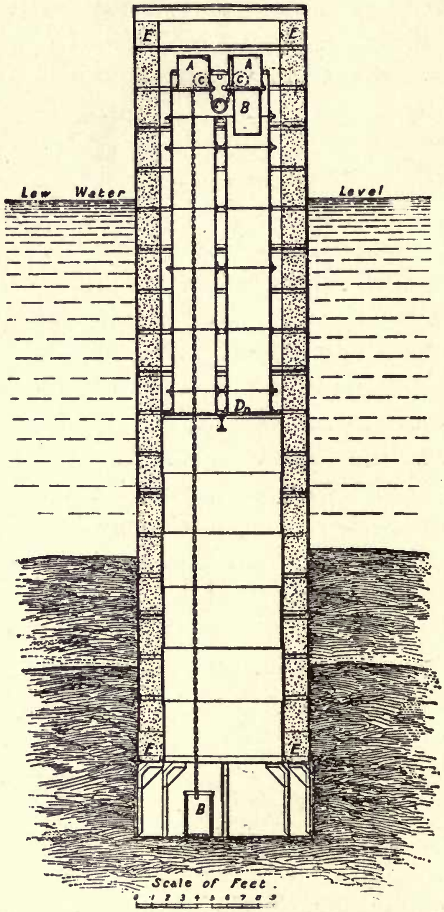


FIG. 108.—The Hughes Air-lock and Shaft: Employed at Valparaiso, Chili.

The cylinders were assembled on a temporary staging, with the inner cylinder bolted to the top of the working chamber and the annular space made water-tight. With the cylinder floating by reason of the annular space, a wrought-iron diaphragm

was bolted onto the top of the inner cylinder, and on this plate were bolted two 3-foot cylinders. When the bottom had been reached the annular space between the cylinders was filled with Portland cement concrete, and all the cylinders were lengthened as needed to keep the tops above the water level.

The air-locks *A* surmounted the two smaller shafts. In each the top door was opened downward by an outside lever attached to the prolongation of the hinge-bar and passing through a stuffing-box. A ring with an india-rubber gasket was attached to the bottom of the lock and the top of the skip-case *B* made an air-tight joint with the lock when hoisted. This skip-case was suspended by two chains of gaged links, one on each side, and these chains passed over the chain-sheaves *C* to the skip-case at the bottom of the adjoining lock.

The lengths of chain were accurately adjusted, so that when both locks are closed at the top one skip-case can be made to descend and the other ascend, by means of a wrench on the outside, with the shaft passing through stuffing-boxes. When the skip-case *B* strikes the bottom of the lock, the compressed air may be let out of that lock and the skip in the case is hoisted out when the top door is opened. The air pressure below forces the skip-case *B* tightly against the ring mentioned.

The skips for material fit closely in the case and they were hoisted out by a steam crane. A pipe was run through each skip near the bottom; as the skip was hoisted out of the lock a bar of iron was pushed through this pipe, and to the ends of this bar the dumping chains were attached. Two men only worked at one time under the air pressure, and these in 4-hour shifts. Though a depth of 107 feet below the water surface was reached in some cylinders, only one death occurred. This death was due to the fact that the man failed to give the proper signal; and the top-men, supposing only material was to be handled, released the air-pressure too suddenly.

Hyde Park Tunnel Air-lock.—The air-lock here illustrated was used in building the Hyde Park tunnel for the Chicago Water Works; Samuel G. Artingstall, M. Am. Soc. C.E., Chief Engineer.

In this work the shafts sunk in the two cribs were made of cast-iron cylinders, 10 feet diameter and bolted together in 8-

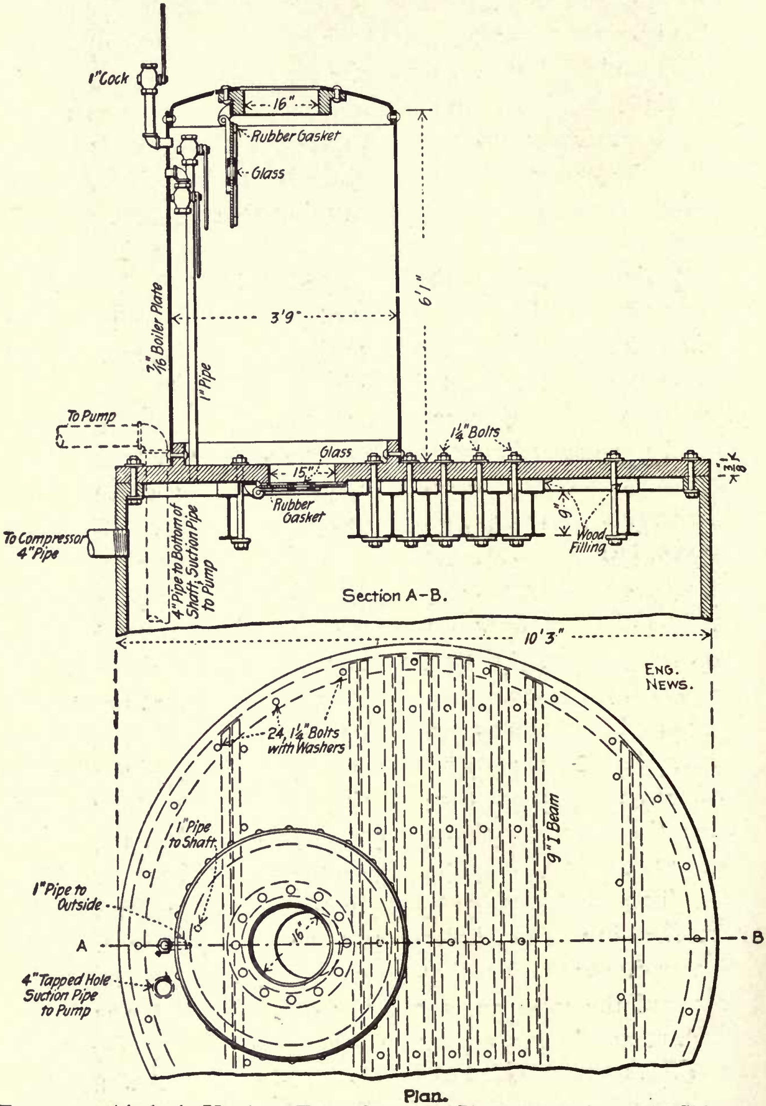


FIG. 109.—Air-lock Used at Top of Shaft: Hyde Park Tunnel, Chicago.

foot sections. After the shafts had been sunk to the tunnel level and the tunnel had been driven about 800 feet from the

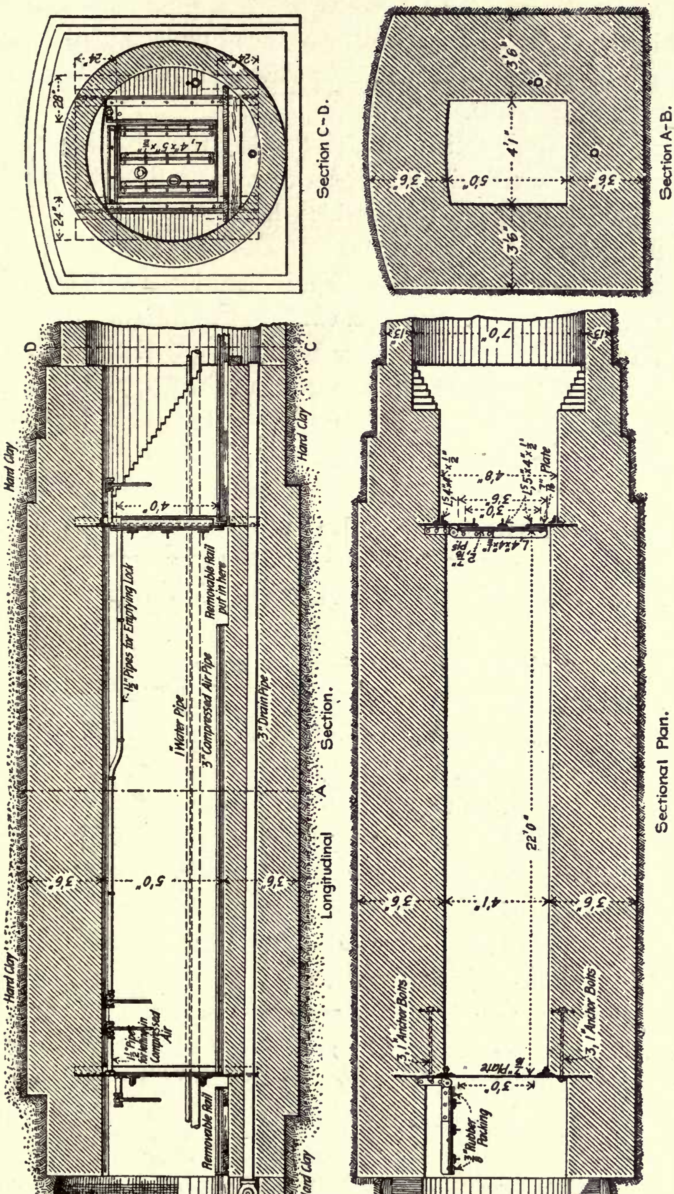


FIG. 110.—Hyde Park Tunnel: Air-lock in 7-foot Tunnel.

shaft, water broke into both drifts. An air-lock was then placed in the drifts and the work continued under air pressure. This air-lock is shown in plan and elevation in Fig. 110, and needs little description.

To re-enter the portion of the flooded tunnel lying westward from the outer crib, an air-lock was placed on top of the shaft. This lock, Fig. 109, is also here shown in sufficient detail to explain its construction.

Morison Air-lock.—The lock here described was used by George S. Morison, M. Am. Soc. C.E., in sinking the pier foundations for the Memphis Bridge over the Mississippi River. The masonry piers were sunk on wooden caissons, 39 to 59 feet high, and reaching to 93 feet below low-water mark, including the masonry piers.

Each caisson was provided with four 24-inch shafts for removing material and finally for sending in concrete to fill the working chamber. Besides these shafts there was a 36-inch shaft with a double air-lock at the bottom, of the ordinary type; and a 6-foot shaft with a special air-lock at the bottom, fitted with an elevator cage for the use of the men.

The clay was removed by the "clay hoist," Fig. 111. This air-lock was placed at the top of the shaft, and behind it was a cylinder and piston; the speed of the piston being multiplied by two sets of sheaves so that the stroke of the piston would lift a bucket from the bottom of the caisson to the air-lock on top. This air-lock is provided with two doors; the one opening into the shaft below is closed by a lever with a balance weight on the outside. The other door, opening into the open air, is worked by a man stationed outside.

The only power used was the air pressure in the caisson, admitted to the bottom of the piston case by appropriate pipes and valves. The bucket carried 6½ cubic feet, and 12 buckets per hour were passed out at a single hoisting shaft. Four hoists were provided, but only two were used at one time.

The special air-lock, also shown in Fig. 111, was fitted with a passenger hoist, which was operated by a hoisting engine placed at the top of the shaft; and this engine could be taken

up by a derrick and quickly replaced when it was necessary to add a section to the shaft. This engine was also driven by compressed air. The upper shaft, through which the elevator cage ran, was a cylinder, 6 feet in diameter. The air-lock was also 6 feet in diameter, and the shaft leading to the caisson was 4

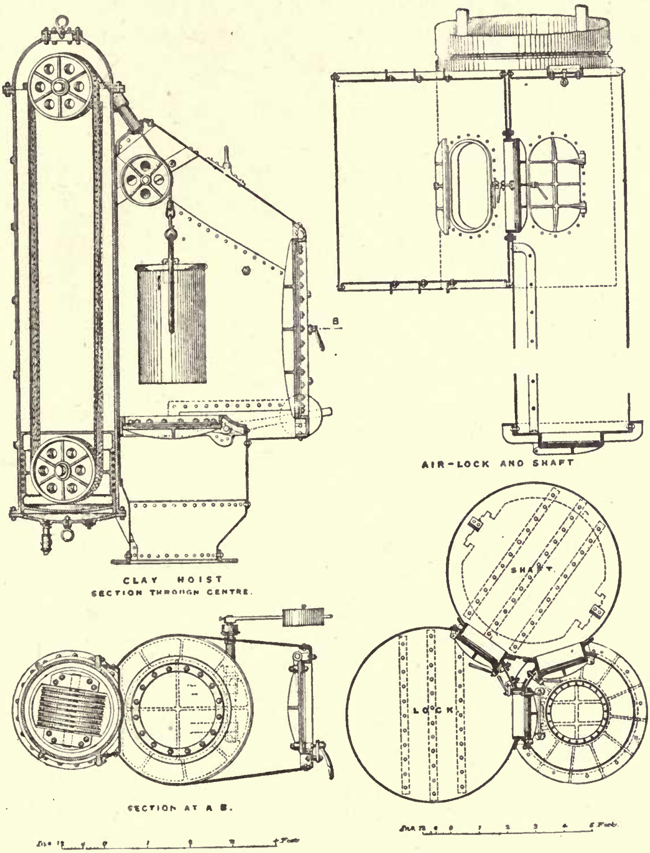


FIG. 111.—Memphis Bridge: Details of Air-lock and Hoists.

feet in diameter. These three cylinders were set side by side, with the shells connected by doors; while a fourth door opened outward at the bottom of the lower shaft. In working, the door between the two upper shafts was always kept closed, and the door in the bottom shaft was open. In an emergency the lower shaft could be used as an air-lock by itself.

Victoria Bridge Air-lock.—The Victoria Bridge was built in 1892 by Charles Neate, M. Inst. C.E., at Stockton-on-Tees, England. The piers were founded on five cast-iron cylinders for each pier, each cylinder 14 feet in diameter. The larger part of the sinking was done by the pneumatic process.

The main cylinder of the air-lock (Fig. 112) was 8 feet high and 5 feet diameter, fitted with a partly boarded floor, but

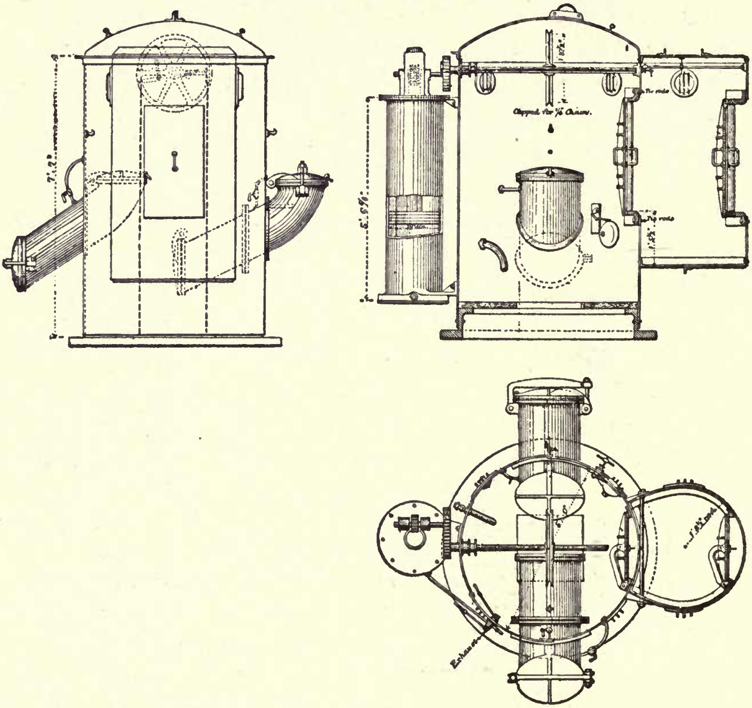


FIG. 112.—Victoria Bridge: Air-lock.

otherwise open to the working chamber. The air-lock proper was formed by a lateral chamber with two doors, as usual. On the side opposite to this is a vertical cylinder, $5\frac{1}{2}$ feet in height and 18 inches diameter. This cylinder is open at the top and carries a piston operated by compressed air, and the piston-rod carries a rack which actuates a pinion and thus revolves a sheave keyed to the shaft inside the main cylinder. The ex-

cavated material is raised by a rope passing over this sheave, the rope rising 10 feet for every 1-foot lift of the rack.

This raised material was to be dumped into a discharge spout fixed in the side of the main cylinder and fitted with the proper doors. But while a similar spout was used for passing in the concrete, it was found advisable to pass the excavated material through the air-lock proper. With this exception, this pneumatic machinery worked well. The concreting was carried up within 12 feet of the lock-floor before the lock was removed. The material excavated was a fine running sand.

Air-locks at Kiel Dry-dock.—The German Government has lately completed at Kiel, a concrete dry-dock in which the subaqueous work was performed by means of a floating pneumatic caisson.

In connection with this device two forms of air-locks were used, one for passing in concrete and material, the other for the use of the workmen. The latter lock is shown in Fig. 113, and

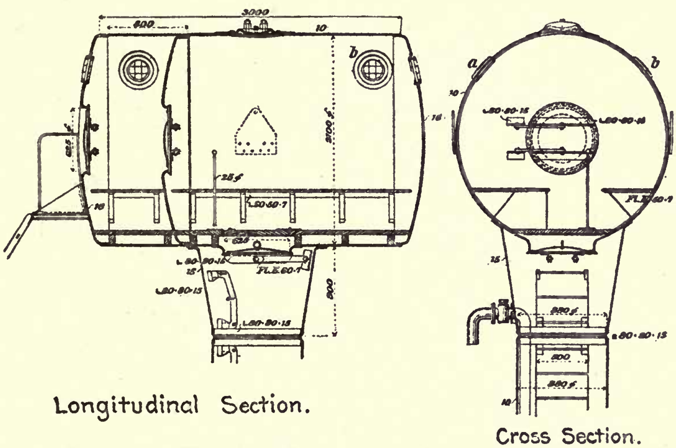


FIG. 113.—Kiel Dry-dock: Air-lock for Workmen.

it constitutes a double air-lock; the outer chamber containing four men, while both chambers together will accommodate twelve men.

The special and altogether novel feature in this lock is an arrangement of valves designed to permit the gradual auto-

matic equalization of pressure between the inside and outside of the lock. The valves are, in fact, automatic regulators and they are operated as follows: When entering the lock, the device gives a uniform pressure increase of 1.5 pounds per minute; when locking-out, the uniform decrease in pressure is only $\frac{3}{4}$ of a pound per minute. This attachment to the air-lock prevents the possibility of injury to workmen as a result of the too rapid transition to or from the compressed-air chamber.

As here shown in Fig. 114, the valve has a small air passage *B* regulated by the needle *E*. This needle is attached to a small piston *C* acted on by the higher pressure on one side, and the lower pressure on the other. The latter pressure is aided by a coil-spring, which tends to force the piston to the end opposite the air-passage *B*, and thus opens the needle passage. The actual position of the needle at any time thus depends upon the difference of air-pressure on the two sides.

Two valves are connected with each air-lock, one for locking-

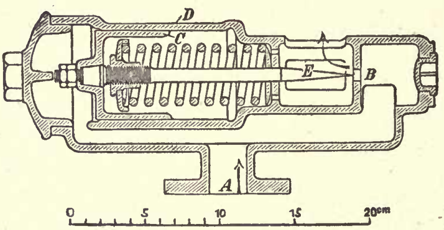


FIG. 114.—Air-valve for Slow Pressure Equalization in Kiel Air-locks.

in and the other for locking-out. In the first case, the compressed air from the supply main enters at *A*, passes through *B* to the discharge openings at *E* leading into the air-lock. The air from *A* also passes around behind the valve-piston and presses the needle forward to a point where it is balanced by the pull of the coil-spring added to the air pressure in the lock. As the lock-pressure increases gradually, the piston is forced back and the opening at *B* is enlarged.

The valve for locking-out is connected to the air-lock by the opening *A*, and with the external air by the opening *E*. The operation is similar to that described above. A separate,

smaller valve, however, admits fresh compressed air to the lock at half the rate of the escaping air, so that the effective pressure

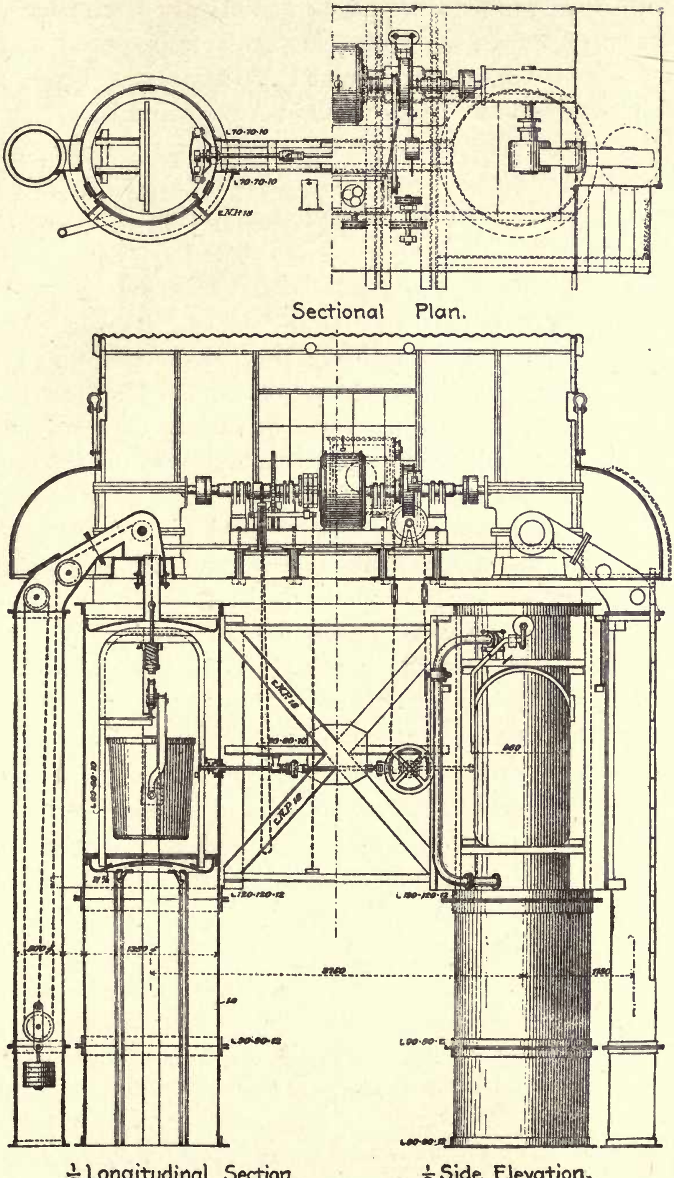


FIG. 115.—Kiel Drydock: Counterbalanced Material Elevators.

decrease is only $\frac{3}{4}$ of a pound per minute, or half the pressure increase in locking-in.

With a caisson-pressure of 30 pounds per square inch, the operation of locking-in, with this regulator, required 20 minutes. The locking-out consumed 40 minutes. These rates would be deemed excessively slow in American caisson practice, but the use of the same principle could be utilized with a valve permitting a more rapid equalization.

These regulator valves are made by Korting Brothers, Hanover, Germany. The engineer in charge at Kiel said that "in general they gave very good satisfaction." But he said that they sometimes failed in cold weather, by reason of ice forming at the needle aperture. Ordinary air-cocks were found useful in giving the sudden increase pressure necessary to tightly close the door; after that the time-valve was used. These ordinary cocks could only be manipulated with special keys in the possession of the inspectors and lock-tenders.

Seven vertical shafts of riveted steel pipe connected the working platform of the floating pneumatic caissons with the suspended working-chamber below. These shafts were made in sections, so that they could be added or removed as the working-chamber was lowered or raised; weight being added or removed by pumping water into or out of cylindrical balance-tanks, in the upper half of the working-chamber. Four of these seven shafts were used for handling material, two were for workmen, and one was for concrete. All of these shafts had air-locks at the upper end and they were closed by air-tight doors at the bottom when changes were being made in length. Of the four material shafts, two were fitted with motor-driven elevators, while two merely had doors at the top and bottom, allowing them to be utilized as a full-length air-lock in passing long timbers into the working-chamber.

The concrete shaft forms a simple chute, with a lining tube, down which the concrete falls. This chute is kept full of concrete, and two lateral hoppers at the bottom permit the contents to be tapped as needed into buckets running on overhead trolleys in the working-chamber. The upper end of the chute is

fitted with a double hopper, both compartments of which discharge into the inner lining of the tube. These two compartments are filled alternately and each has an air-tight trap door at top and bottom, so that one can be filled while the other is discharging into the chute. These two sets of doors are interlocked so that only one can be opened at a time. The small air-lock at the side of the top end of the chute serves to admit two laborers into the space just beside the hopper, for operating the bottom doors of the hopper compartments.

The two material elevators are arranged as shown in Fig. 115. The two shafts, side by side, are fitted with two hoisting skips, counterbalanced through their connection to the same hoisting-motor shaft. By a worm-gearing this shaft drives a lifting sheave over the center of each shaft, a sprocket chain attached to the skip passing over this sheave. The slack in the chain is taken up by a three-post rigging held taut by a weight contained in a small air-tight auxiliary well at the side of the main shaft. The hoisting motor is automatically shut off and a brake is applied when either skip nears its highest position. To draw the skip up so that its bottom plate forms an air-tight seal against the bottom ring of the air-lock, a hand-hoist is thrown into gear by a foot-lever, which latter also releases the brake.

The skip is a skeleton frame carrying a horizontal track rail, on which runs a trolley carrying the bucket. When the skip is at the top or bottom this rail registers with a similar track-rail, and the bucket is thus quickly run into or out of the skip-frame.

CHAPTER XIII

TUNNEL NOTES

The freezing process for shaft-sinking—Its application at Ronnenberg and at Iron Mountain—Tunnel rock-temperatures—Definition of quicksand—Making concrete water-tight—The hand-auger in prospecting work—Tunnel cross-section instrument—Coxe's plummet-lamp.

The Freezing Process for Shaft-sinking.—This process was invented by F. A. Poetsch, a German engineer, and was first successfully employed by him in 1883-4, at the Archibald lignite mine, at Schneidlingen, Germany. The process is expensive and is only used in penetrating water-bearing strata where other and less costly methods fail.

This method of shaft-sinking may be generally described as follows: Around the site of the proposed shaft and at some little distance outside of the dimensions determined upon, is sunk a circle of pipes, 6 to 8 inches diameter, and penetrating the rock or other impermeable material underlying the water-bearing stratum. The sinking of these pipes is one of the expensive features of the plan, as boulders and other obstructions may be encountered. When sunk these larger pipes are closed tightly at the bottom, and in the center of each is inserted a smaller circulating pipe, not quite so long as the large pipe and open at the bottom. At the top, these two systems of pipes are then connected by other pipes leading to the brine pump. With the pipe system in place a freezing solution is forced by the pump down the inner tube and up in the annular space surrounding this inner tube. The final result of circulating this saline solution through the pipes is to extract whatever heat there is in the soil surrounding the pipes, and after a sufficient time to freeze solidly a ring of material surrounding the site of

the shaft, this ring excluding the outside water and permitting excavation and lining in the open.

The freezing operation is kept up until the work has advanced sufficiently to avoid all danger from thawing. As the shaft built will in time again be surrounded by water-bearing material, the lining must be made water-tight by iron cylinders or other construction; and the connection with the rock at the bottom must also be made so as to permanently exclude water. With this general description, the method is further explained in the specific cases here noted.

Freezing Process at Ronnenberg.—Soundings made by the Alkali Society of Ronnenberg, Germany, showed that a bed of salts of potash lay at a depth of 459 feet below the surface. To the depth of 407 feet the ground was largely composed of a much fissured and very irregular gypsum formation permeated with water; a 50-foot bed of hard and compact gypsum lay immediately over the salt formation.

After the failure of other methods it was determined to try the freezing process. But as the water met with contained 3% of salt at a depth of 105 feet, some experiments were made to ascertain whether the freezing process would be successful under these conditions. Tests were made with saline solutions of 4, 8, 10 and 12% of $NaCl$; and these solutions were submitted for 24 hours to a temperature of 12°C. At the end of this time it was found that the 4% solution was almost solidly frozen; the others less so, and the 12% solution was little affected by the cold at the end of 48 hours.

The installation included 30 tubes sunk to a depth of 413 feet in a circle 29½ feet in diameter. The freezing machines were double the capacity of a plant intended for a non-saline soil. Five months were consumed in sinking the tubes and in making the necessary connections; and in 39 days after the actual freezing operation was commenced, the temperature at the bottom of the shaft was 4°C. The machines were kept in operation for 20 days longer before the excavating of the shaft was started, and after considerable work had been done upon the shaft one of the two freezing machines was stopped. The

excavation near the wall of the shaft was done by hand, explosives being used carefully in the central core. The inside diameter of the masonry lining of the shaft was 18 feet.

Mining Shaft at Iron Mountain, Mich.—Mr. Charles Sooysmith, M. Am. Soc. C.E., as the owner of the Poetsch patents in the United States, has made a very careful study of this method, and the following notes relate to his experience in sinking a mining shaft at Iron Mountain, Mich.:

At this shaft 8-inch pipes were sunk in a circle 29 feet in diameter, through water-bearing soil, to a depth of about 90 feet. The material was coarse and fine sand, with occasional layers of boulders.

Chloride of calcium brine, cooled by an ice-machine to about 5°F., was circulated through the system of pipes installed. In 39 days the frozen area extended 4 feet 5 inches outside the circle of pipes and to a somewhat greater distance inside. In 70 days the inside distance was 11 feet from the circle of pipes. As the frozen wall was unnecessarily thick the ice-machine was only run sufficiently to maintain the wall secured. This wall did not thaw out sufficiently to admit any water until 50 days after the completion of the shaft.

From experiments made Mr. Sooysmith concludes as follows: But a small proportion of the cold will be expended in cooling the earth outside of the frozen mass. For example, if the material is frozen 5 feet outside the line of excavation necessary, it would require only about 12% of the total freezing capacity to cool the material for a distance of 8 feet outside of the frozen mass from a temperature of 32°F. to 1°F. below the normal temperature of the material. The interior of the frozen mass is cooled far below the freezing point, and so acts as a reservoir of cold. It should be remembered, in connection with this freezing process, that a cubic foot of chloride of calcium brine will—for each degree of temperature—carry about 60 thermal units, or about 300 times as much as a cubic foot of air at atmospheric pressure. As the circulating pipes are in direct contact with the soil, the freezing effect is correspondingly rapid. The absolute conductivity of frozen soil is about

20; or, 20 British thermal units will pass through a body of frozen soil 1 foot square and 1 inch thick in one hour with a difference of temperature of 1°F.

Tunnel Temperature.—In the Simplon tunnel temperature observations have been regularly made, taking the temperature of both the rock and the air in the tunnel. As the figures as given for the temperature of the air vary largely with the amount and kind of ventilation, the following average temperatures are for the rock only:

North Heading— Dist. from portal, feet.	Temp. Fahr.	South Heading— Dist. from portal, feet.	Temp. Fahr.
1,640	54.3°	1,640	56.2°
3,280	57.5°	3,280	61.2°
6,560	63.6°	6,560	69.7°
9,840	70.3°	9,860	74.7°
12,920	76.3°	11,150	86.9°
15,090	86.3°	11,810	87.6°
16,400	89.1°		

The maximum observed temperatures have been 92.2°F. in the north end, and 88.7°F. in the south end. The water flowing from the rock has sometimes had a temperature of 91°F. The normal amount of ventilation required during the summer of 1901 was about 39,000 cubic feet of free air per minute, forced in, at the north end, and 66,000 cubic feet per minute at the south end.

What Is Quicksand?—One of the most troublesome materials dealt with in tunneling operations is quicksand; yet there are few materials about which there is such a diversity of opinion as to its constituent ingredients. One dictionary defines quicksand as "A large mass of loose or moving sand mixed with water"; and another similar authority calls it "A mixture with water of rounded particles of sand and clay, the sand predominating."

Probably the best discussion of the real character of quick-

sand is found in The Transactions of the American Society of Civil Engineers, Vol. XLIII, p. 582. In the course of this discussion Mr. Allen Hazen, M. Am. Soc. C.E., defines quicksand as "An even-grained sand, containing for the time far more water than would normally be contained in its voids, and, therefore, with its grains held a little distance apart, so that they flow upon each other readily." Mr. Hazen goes on to say that this sand may be either fine or coarse, but it is usually extremely fine. It may contain a little clay and still act as quicksand; but a material containing considerable clay is cohesive and impervious to water. Water may press this mixture of clay and sand out of place or make cracks in it, and under heavy pressure it may flow slowly. But such a compound will never make an intimate liquid mixture with water capable of flowing through small openings and behaving like water. This latter is the characteristic property of quicksand.

Quicksands are usually fine sands, says Mr. Hazen. With an effective size of grain from 0.20 to 0.30mm., an upward velocity of 5 to 12 feet per second, the usual velocity of ground water about an excavation, will not lift the sand. It would require an unusually strong ground-water current to make sand of this coarseness act as quicksand. But if the sand grain has a diameter of 0.10mm., it only requires a current velocity of 16 inches per hour to lift it, and this velocity is very common. When sand of 0.05 and 0.03mm. is found in pervious materials, it is thus sure to act as quicksand.

Making Concrete Water-tight.—The increasing use of concrete for tanks, reservoirs and conduits of various kinds has naturally turned the attention of engineers to securing water-tight construction. To do this two paths are open to the engineer: he may employ some form of waterproofing, or he may so manufacture his concrete that it will be waterproof. In actual practice, however, the latter method of solving the problem is usually a very expensive and difficult operation. We may review some of the more usual processes for waterproofing concrete, as follows:

The most common practice is to use some kind of asphalt

coating, employed either alone or in combination with tarred or asbestos felt. In the latter case the felt is laid to break joints and the asphalt is spread under, between and over the felt, and the whole is then covered by concrete. There are usually three to six layers of felt, and the asphalt is always of the best grade of Bermuda or Alcatraz lake-asphalt. The ultimate durability of this waterproofing is yet unknown, though it is extensively used in subway work.

When asphalt alone is used the concrete surface is first plastered with a rich mortar, on which the asphalt is mopped to a thickness of $\frac{1}{8}$ inch, and then plastered over before the remainder of the concrete is deposited. Asphalt mastic is usually laid directly on the concrete to a depth of about $\frac{1}{2}$ inch, and is then covered directly by the concrete.

In Europe, where many tanks and conduits have been built of reinforced concrete, the only waterproofing used is a layer of rich cement mortar about 1 inch thick. This mortar coating is preferably built up with the concrete, and is placed on the inside. For water pressures of over 50-foot head, European engineers deem it necessary to line with sheet-steel all reinforced cement pipe; though the pipes referred to usually have very thin shells. European and American experience with tanks and conduits indicates that all practical requirements for water-tightness are secured by a wet mixture and a cement mortar coating.

A number of experiments have been made in producing impermeable concrete, both in Europe and in the United States. The object was either to determine a mixture of cement and aggregates that would resist the percolation of water, or to discover some substance that, mixed with the cement, would render the hardened product impermeable. Mr. R. Ferat, of the Boulogne Laboratory of the Ponts et Chaussées, after five years of experimenting, came to the following conclusions:

"The minimum permeability is found in mortars where the proportion of medium-sized grains is small, and the coarse and fine grains are about equal to each other."

His experiments also showed that the permeability of mor-

tars submitted to a continuous filtration of fresh or sea water diminishes rapidly with time. He also advocates a too large dose of mixing water rather than a too small quantity. Other experiments tend to show that fine sand is better than coarse sand, and with the same sand permeability increases as the proportion of cement increases.

In connection with the admixture of other materials with the cement, Mr. R. W. Lesley, Assoc. M. Am. Soc. C. E., advocates a reasonable proportion of slaked lime to the concrete when mixing. The experiments of Prof. de Smedt show that this lime does not injure cements or mortars; does not cause expansion; and does not decrease the strength, though it does slightly retard the setting of the mortar. The advantage of the lime in the mass is that it tends to close the pores, to form efflorescence or deposits on the surface, and should largely aid in making mortars impermeable. But no extended experiments have yet been made exactly in this line.

Silicate of soda and soap and alum have been mixed with cement in an attempt to make the mortar water-tight. Prof. W. K. Hatt conducted experiments with these mixtures. He found that the effect of the silicate of soda diminished the strength of the mortar more than 50%, and diminished the absorption of ash mortars about 50%. The soap solution alone does not increase the strength, but does decrease the permeability about 50%. The effect of alum and soap was to strengthen the mortar and harden it, with 50% decrease in absorption. Prof. Hatt used a 5% solution of ground alum and water, and a 7% solution of soap and water. The alum water was mixed with the mortar in the proportion of one-half the ordinary gaging water; the soap solution was then applied to bring the mortar to the desired plasticity. The soap and alum acting together cause the precipitation of an insoluble compound in the pores of the mortar.

The report of the Chief of Engineers, U. S. Army, for 1902, contains some interesting notes on the waterproofing of concrete, now so extensively used in fortification work. Experiments made at Fort Armistead, near Baltimore, showed con-

clusively that there was less resistance to the passage of water through 30 feet of concrete than to its passage through sandy soil.

In building heavy gun emplacements with Portland cement concrete, the use of asphalt has been largely abandoned as a waterproof covering. Instead, a coating of roofing paint is applied over the concrete steel ceiling, and on this is laid, like shingles, three layers of asbestos felt; this is again coated with roofing paint, and then covered by a $1\frac{1}{2}$-inch layer of poor mortar, made of one part cement to six parts sand. Above this mortar is placed ordinary concrete. It is expected that cracks will not extend below the felt. In building powder magazines lead sheets are used instead of the asbestos felt.

In a case where unequal settlement produced cracks in the concrete, linseed oil was successfully applied on the surface. Large cracks were filled with cement grout, and the linseed oil was applied as long as it would be absorbed, in cracks and on the surface.

In another case, asphalt diluted with petroleum residuum oil was used; and the groove made at the surface of the concrete, over the crack, was filled with asphalt.

An alum-and-lye waterproof wash, employed on the fortifications at the mouth of the Columbia River, was made as follows: One pound concentrated lye and 5 pounds of alum to 2 gallons of water constituted the "stock." To 1 pint of the stock 10 pounds of cement were added, thinned out with water until the mixture could be applied with a kalsomine brush. This is applied to the plaster until it fills all the pores. This surface, if too dry, should be wet with a brush, ahead of the waterproofing. The wash should be applied as soon as possible after the plaster has set, but never when the walls are too warm or the sun is shining brightly. It will not adhere well to old work. .Two coats are sufficient; and plastered concrete so coated has successfully withstood a head of 10 to 12 feet of water for days at a time.

In the Pennsylvania R. R. tunnels, now being constructed in New York City, the problem of waterproofing these tunnels

has been deemed of sufficient importance to warrant the issue of special and revised specifications for this work. An abstract of the specifications follows:

The tunnel lining will be concrete walls, filled in behind suitable forms, surmounted by a brick arch. After the forms are removed the surface of the concrete, inside the tunnel, is given a ½-inch coat of mortar, made of equal parts, by volume, of Portland cement and sand, and troweled smooth. After this mortar has set and dried out, it is covered with alternate layers of coal-tar pitch and felt; seven layers of pitch and six of felt. This pitch is specified as "straight-run coal-tar pitch, which will soften at 60° Fahr." The pitch is mopped onto the surface to a uniform thickness of not less than 1-16 inch; and the felt is laid immediately on this, with the sheets overlapping not less than 12 inches on all edges. This first pitch-and-felt lining extends from the bottom to a point about 20° 30′ above the springing line of the tunnel.

The roof of the tunnels is covered with two triple layers of felt and seven layers of pitch laid on the brickwork. The triple layers are made up as above described, and laid, with a lap of 2 inches to 6 inches, on a bed of pitch which will soften at 30° Fahr. With the second triple-felt layer laid in a similar manner, these waterproofing courses are covered with one course of brick laid flat in ½-inch bed of mortar, made of equal parts of cement and sand, with the joints completely filled with this same mortar.

Engineers have also found the following method of waterproofing successful for arches, abutments, and retaining walls: For a first coat, asphalt cut with naphtha is applied as a paint to the concrete surface when this is perfectly dry. Then an asphaltic mastic is applied, made of 1 part asphalt to 4 parts sand, and thoroughly smoothed with hot irons. It should be observed that it is extremely difficult to make hot asphalt alone adhere to dry concrete, hence the use of the naphtha. The cost of the waterproofing here described ranges from 10 to 20 cents per square foot of surface, depending upon local conditions.

Hand Auger in Prospecting Work.—Prospecting work, in

comparatively soft material, is sometimes useful in arriving at the pitch of strata, and in otherwise determining underground or subaqueous conditions. In a paper presented to the American Institute of Mining Engineers, Charles Catlett, M. Am. Inst. M. E., describes as follows the set of tools required for this work:

(1) An auger bit of steel or Swede iron, with a steel point twisted into a spiral, with an ultimate diameter of 2 inches and an ultimate thickness of blade of not less than $\frac{1}{4}$ inch. The point is more effective when split; and a length of 13 inches was found to be the maximum for good work. The 13-inch auger contains four turns; and this is welded to 18 inches of 1-inch wrought-iron pipe, with screw-threads for connection.

(2) One piece of $1\frac{3}{8}$-inch octagonal steel, 12 inches long, with a 2-inch cutting edge. This is also welded to 18 inches of pipe, with thread cut for connection.

(3) Ten feet of $1\frac{1}{4}$-inch iron rod, threaded for connection with 1-inch pipe at one end. Connected with a drill-bit, this rod is used as a jumper in starting holes in hard material. It also gives additional weight to the drill in penetrating rock.

(4) Section of 1-inch pipe and connections.

(5) An iron handle, 2 feet long, arranged with a central eye for sliding on the pipe, and a set-screw for fastening to the pipe.

(6) A sand-pump; made of 1 or 2 feet of 1-inch pipe, with a simple leather valve and a cord for lifting it.

(7) Two pairs of pipe-tongs; or two monkey wrenches, with attachments for turning them into pipe-tongs.

(8) Sundries: Twenty-five feet of tape, oil can, flat file, cheap spring-balance, water bucket, etc.

The auger is used by two men up to 25 feet, and three men to 35 feet; for borings from 35 to 50 feet deep a rough frame or trestle is required for the third man to stand upon. For borings over 50 feet it is generally necessary to remove one or two of the top pipe sections when the auger is lifted.

In drilling, just enough water is continually used to soften the material. In hard material the drill-bit is screwed and

worked as a churn drill. With either the auger or drill, the material extracted is washed, and a sample is preserved of the stratum penetrated. After washing all the material in one stratum, the washed material is mixed, and a sample is put into a bottle and labeled. An accurate record of the borings is essential; and to this end the foreman is instructed to write down everything in a small notebook, trusting nothing to memory.

The proper classification of the materials obtained from a test-boring of any kind is extremely important, if these tests are to be of any real use to a prospective bidder upon the work. The usual method is to specify the depth of the individual sample, as measured from the surface, and the thickness of each stratum.

Cases occur where this information is misleading, especially where the classification may be in terms not plainly understood by the bidder.

It has been suggested with some force that a better classification is one adding to the statement of general depth and thickness, a column showing the time consumed in penetrating the several strata. This, at least, would be a close physical classification; and it would certainly assist in arriving at a more intelligent conclusion. It costs no more than the present method.

It is well, in work of this kind, to use a 20-foot hoisting gin, equipped with a 6-inch block and fall, and 100 feet of $\frac{3}{4}$-inch rope. A Yale & Towne $\frac{1}{2}$-ton differential chain block is also very useful in pulling up the pipe.

The hoisting gin must be portable. It is made to fold up, and is used as a platform to carry the pipes, etc., lashed to it. This gin can be made of three pieces of 4 x 4-inch spruce timber, each 20 feet long. The top of each piece is chamfered, and a bolt is inserted to prevent splitting. The middle piece is chamfered on two sides, and the others on one side only. A $\frac{3}{4}$-inch bolt, with a square head and slot with pin or dowel, passes through the three sticks; and from this is suspended a $\frac{3}{4}$-inch round iron "bail," with a "drop" sufficient to permit

it to pass freely over the top of the middle leg. Cleats nailed to the middle leg form a ladder.

Tunnel Cross-section Instruments.—Various devices are used for cross-sectioning a completed rock tunnel, or for comparing the actual contour of the tunnel and all its irregularities with the theoretical or contract cross-section.

In the new Croton Aqueduct tunnel, these contours were taken every 10 feet over a length of 30 miles; and F. W. Watkin, M. Am. Soc. C. E., devised an instrument which was more accurate and more convenient to operate than the older forms.

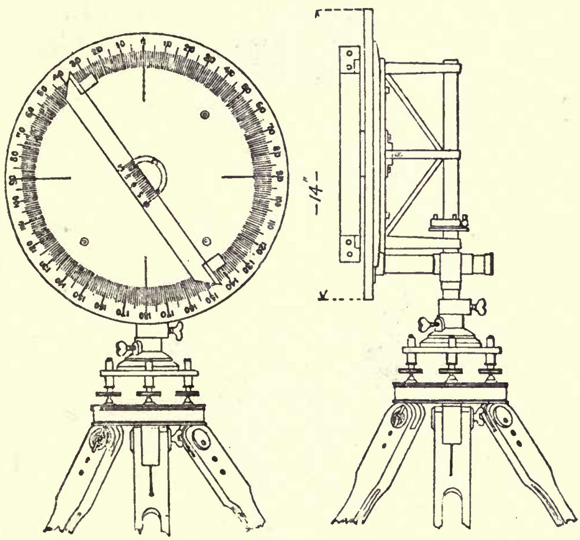


FIG. 116.—Cross-section Instrument for Tunnel Work.

The circular disk was 3 feet in diameter, and it was attached to a vertical iron rod which slid up and down in a socket and could be regulated by a thumb-screw. The disk and rod were supported by a tripod with extension legs.

The disk was set at right angle to the axis of the tunnel, and its center was raised to coincide with the tunnel center. Cross-sections were then taken with a light, graduated rod, and the measurements would show at once if any trimming were necessary.

About the same time Alfred Craven, M. Am. Soc. C. E., devised the instrument illustrated in Fig. 116, which is more portable than the other. The circular disk was 18 inches in diameter, and was attached to a vertical brass tube mounted on a shifting top, ball-and-socket joint, and leveling screw tripod head. The disk was graduated from 0 at the top to 180° at the bottom, for each degree of the circle. A hardwood arm or rest revolved on a central pin on the face of the disk.

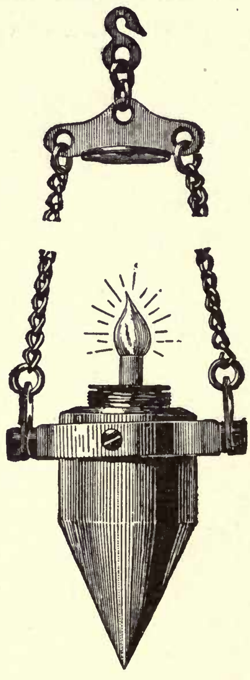


FIG. 117.—Plummet-lamp for Tunnel Work.

On this was placed a wooden measuring rod, 14 feet long, tapering from 2 inches to ½ inch, and graduated for feet and tenths from the small end. This rod, resting on the arm, was slid out to touch the rock at any point, indicating the radial distance from the center line and the angle from the vertical.

The disk must be at right angle with the axis of the tunnel; and to insure this a small sighting tube was attached to it, in

line with the tunnel axis, and set on a distant line light. The elevation of the center of the disk was taken before the cross-section was measured.

From 15 to 20 measurements usually covered all prominent irregularities at any one station. These were recorded like ordinary cross-section notes. The disk diagrams were plotted in the office by using a 3-inch German silver circular protractor, graduated both ways from 0 to 180°, and provided with a horn center. A graduated metal arm swings about the center and marks the distances out. The areas were generally measured by a polar planimeter.

Plummet-lamp.—The plummet-lamp was first introduced by the late Eckley B. Coxe, especially for use in mine surveying.

As shown in the illustration, a large brass plummet is hollowed out in the upper part, as a receptacle for oil, and this is fitted with a wick, placed in the axis of the plummet. This plummet is suspended by two chains attached to a compensating ring, connected with the plummet by two small screws with conical points.

When required, these lamps are fitted with a safety, or fire-damp attachment, resembling that used with the Mueseler lamp.

In use, these lamps are suspended from screw-eyes driven into a wooden plug in a hole drilled in the roof of the tunnel. The string is tied to the screw-eye and placed in exact line, and left there; whenever a line-sight is wanted the plummet-lamp is attached to the string. At the present time various forms of these plummet-lamps are furnished by instrument makers.

CHAPTER XIV

THE CONSTRUCTION OF THE SIMPLON TUNNEL

Water-works tunnel at Cincinnati:—Telephone and freight transportation tunnels in Chicago.

The following description of the longest of the Alpine tunnels is taken from a contribution to *Engineering News,** made by Mr. C. R. King, who visited and carefully studied the work in progress. Mr. King's story of the history of the enterprise, and its importance as a link in railway transportation in Southern Europe, has been somewhat condensed.

Much of the matter here described would fall under various chapter heads. But it has been deemed better to present it in this place consecutively and together, as better illustrating what may be termed the latest tunnel practice among European engineers. The same remark applies to the other two articles coming under this chapter head.

Simplon Tunnel.—The Simplon Pass is one of the most noted of the Alpine passes, and the Simplon Pass road was built in 1806 by Napoleon. Projects for tunneling the pass have been many. In 1857 Mr. Clo-Venetz proposed a high-level tunnel, 7.5 miles long; and, in 1860, the French engineer, Vauthier, planned a tunnel 11.3 miles long, or the first of the low-level projects. The Simplon Company, organized in 1875, gathered together much data of value to the proposed work; and in 1893 the Jura-Simplon Railway Company entered into a contract with Brandt, Brandau & Co., of Winterthur, Switzerland, to construct a tunnel from Brieg, on the north side, to Iselle, on the Italian side of the Simplon Pass. The general route of this tunnel is shown in the accompanying map; and it is practically the same as that laid down, in 1875, for the old Simplon

*For the complete article see *Engineering News,* August-September, 1903.

Company, by Mr. Louis Favre, the contractor for the St. Gothard tunnel.

The plans were finally approved in their engineering features by a commission of noted engineers; and by the treaty of Nov. 25, 1895, between the Italian and Swiss governments, the Jura-Simplon Railway Company was permitted to construct and operate the tunnel line lying between Brieg and Domo d'Ossola.

The Simplon tunnel line cuts the territory lying between the St. Gothard and the Mont Cenis tunnels. Its construction will especially benefit the Paris, Lyons & Mediterranean, the

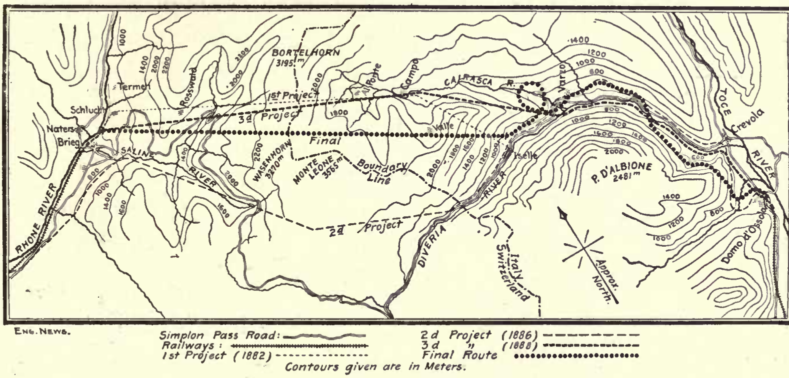


FIG. 118.—Simplon Tunnel: Map Showing Various Routes from 1832 to 1893.

Jura-Simplon and the Italian Mediterranean railway companies; and the territory best served by it will be French Switzerland and northeastern Italy, or Piedmont and Lombardy. It will save from 3½ to 5 hours in time of transit between Paris and Milan, and shorten the London-Brindisi route about 180 miles.

As the Italian railway system ended at Domo d'Ossola, some miles south of the tunnel terminus at Iselle, the Italian government contracted, in the treaty of 1895, to build the connecting line between these points, as shown on the map. The Italian government is also building a new line from Milan to Domo d'Ossola. This new railway includes various features of en-

gineering interest, and some of its more important works are here noted.

The new line from Milan starts at Gallarate, on the existing line, and follows the west shore of Lake Maggiore, and thence proceeds directly north to Domo d'Ossola and Iselle. The grades have been much reduced. While the grades of the existing line are 1%, and occasionally 1.6%, those on the new line do not exceed 0.6%. The tunnel at Farragiana is one of the most notable works on the Arona-Domo d'Ossola section, though there are many small tunnels. This tunnel is 12,000 feet long, and penetrates a very hard porphyric rock. The new line saves 11 miles in distance between Milan and Domo

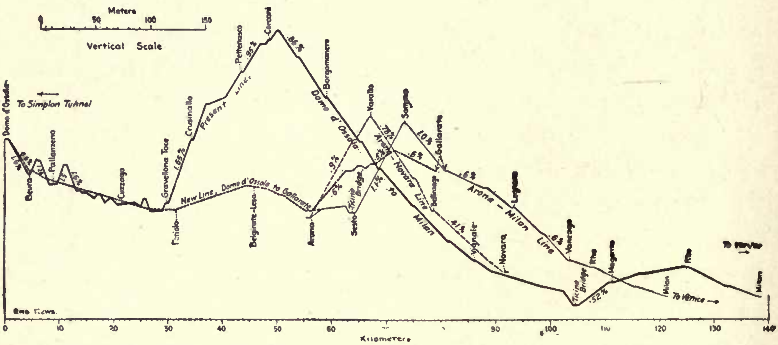


FIG. 119.—Profiles of Existing and Proposed Railways at the Italian End of the Simplon Tunnel.

d'Ossola; and, with its improved gradients, greater loads and higher speeds will be possible.

The Domo d'Ossola-Iselle section, 11½ miles long, is built through a region of extremely diversified topography, necessitating numerous tunnels and stone arch bridges, viaducts, etc. The maximum gradient is 2½%, and the longest tunnel, at Trasquera, is 5,656 feet long. The seven tunnels on this 11½ miles aggregate in length over 4 miles.

The Working Plant and Its Accessories.—The contract time for constructing the Simplon tunnel, 12.4 miles long, was five and a half years, and the course of events has shown that this allotted time was none too long. To carry on a work whose

duration was half a decade, the two parts of which were separated by a dozen miles, and the whole of which was located far from the nearest centers of mechanical industry, obviously necessitated a working plant of unusual dimensions. This working plant had, moreover, to be divided into two separate plants, one at each end of the tunnel, each independent of the other and complete in itself. Each plant had to supply power to provide means for ventilation, illumination, air refrigeration, drainage and transportation service. For each plant there had also to be workshops in which machinery and tools could be repaired. There had then to be provided houses for the workmen and engineers, water supply, hospital service, sanitary conveniences, stores for provisions and materials, and a multitude of minor necessities.

The two plants at the opposite ends of the tunnel are, as nearly as possible, duplicates. At the Swiss end the entrance is located 2 miles east of Brieg, at 685.7m. (2,246 feet) altitude, beneath the hills rising from the bank of the River Rhône, and on this narrow and level bank the working plant is laid out with great uniformity. At the Italian end the plant is located in the deep valley, or the Val Verde, at the upper end of which are the tunnel entrances; and the topographical conditions here are such as to prevent a regular layout. The following description of the various installations of the working plant applies, with very few exceptions, to both the Swiss and Italian ends; but the specific structures described are those at the Italian end, unless otherwise stated. For the sake of convenience, the description is divided under the following heads: Power Installations; Ventilation; Air Refrigeration; Illumination; Drainage; Workshops; Buildings and Accessories; Transportation Service.

Power Installations.—Water power is employed for practically all purposes at both ends of the tunnel. At the Swiss end, about 2½ miles upstream from the tunnel entrance, the River Rhône is dammed, and the water collected into a number of reservoirs, provided with necessary gates for controlling the inflow and outflow. From these reservoirs the water is

conveyed for about two miles in a reinforced cement flume. This flume crosses a flat and well-cultivated plain; at the point where this plain drops steeply to the Rhône valley the conduit changes from rectangular flume to two cast-iron pipe lines in trench, which reach to the power house, a distance of about one-half mile. An air inlet pipe located at the brow of the hill serves both penstocks. The total power available from this service is 2,200 horse-power.

At the Italian end the power is derived from the Diveria, about 2½ miles above the works, and near Gondo, the last village in Swiss territory. Here the river is dammed and the water collected into a forebay 80m. (262.5 feet) long, from which it is admitted into a delivery reservoir having a superficial area of 270 square m. and a depth of 2½m. (8.2 feet). At the lower ends of these reservoirs there are overflow weirs, washout sluices, and the regulating gates for controlling the supply to the penstocks.

From the gate house the penstock, for a distance of 1,300m. (4,265 feet), is carried along underneath the Simplon road, and consists of cast-iron pipe 90cm. (2.95 feet) in diameter, built in 6m. (19.68 feet) lengths, with shells 1 inch thick, each weighing 4,400 pounds. This pipe was furnished by W. Bosshardt, of Zurich, Switzerland. Near Paglino, and about 24m. (78.74 feet) before the termination of the cast-iron pipe line, there is an escape pipe, with an adjustable disk cover, designed to reduce the pressure from 118 pounds to 103 pounds per square inch. This escape pipe was continually bursting under the water pressure.

At the end of the first 1,300m. (4,265 feet) the cast-iron penstock is replaced by one of wrought-iron pipe of the same diameter. This wrought-iron penstock continues to the power plant, 2,840m. (9,317 feet), and has ¼-inch shell. It was supplied by Rieter & Co., of Winterthur, Switzerland. This pipe line is carried along against the wall which retains the Simplon road, being supported on granite piers, and enveloped in a sort of matting, which serves, in a degree, to protect the metal from variations in temperature. A little above Iselle the pipe line is

carried across the Diveria by a suspension cable. Further on a jutting bluff is penetrated by a tunnel 282m. (925 feet) long. Here, also, the penstock is enlarged to a diameter of 1m. (3.28 feet) for a length of 181.7m. (596 feet) above the power-house turbines. The total head of water on these turbines is 170m. (558 feet), but the turbines of the ventilation house further upstream work under 10m. (32.8 feet) less head. It should be noted also that pressure at the power-house turbines can be varied from 13 to 17 atmospheres by means of the escape valve at Paglino, previously described. Just before reaching the power station the pipe line again crosses the Diveria, this time on a double-deck bridge. This bridge also serves to connect the high road with the station, and for the carriage of materials between the works on the opposite banks of the river. It was constructed by the Sociéta Nazionale delle Officine di Savigliano, of Turin, Italy.

The power house contains three Pelton wheels, furnished by the well-known firm of Escher, Wyss & Co., of Zurich, Switzerland, two being 250 h.-p. each, and one of 600 h.-p. All three wheels are horizontal, and run at 170 revolutions per minute. They operate the pressure pumps to accumulators supplying water to the rock drills. There are five of these pumps, the first four being operated by the two 250 h.-p. turbines, and the fifth by the 600 h.-p. turbine. The transmission shafting from the turbines to the pumps is so designed that any one of the ten pumps can be thrown out of connection at will. They are geared directly to the water-wheel shaft, and are thrown into and out of connection by a sliding spur wheel on the pump shaft. Three of the pumps have plunger diameters of 48mm. and 68mm., with 660mm. stroke, and, at 78 revolutions, furnish 6 liters of water per second. The remaining two pumps have plunger diameters of 60mm. and 85mm., and a stroke of 1m.; and they discharge 12 liters of water per second at 65 revolutions. The highest pressure of water possible with these pumps is 120 atmospheres per square centimeter.

The water for the pumps is taken from two sources. The first is an 8-inch pipe connection with the penstock, and the

second is the Rovale torrent, on the heights above the portals of the tunnel. The Rovale water is used for the pumps so long as the quantity supplied is sufficient, but in times of shortage resource is had to the penstock supply. In both cases the water is cleaned of all sediment by being passed through filter beds before being delivered to the pumps.

This battery of pumps is calculated for a capacity of 40 liters per second at a pressure of from 40 to 120 atmospheres (64 gallons per minute at 1,175 pounds per square inch); but the present average supply, which suffices for the drills, injectors, etc., is 20 liters per second at 90 atmospheres per centimeter. It may be mentioned here that the quantity of water used in each drill cylinder is one liter per second; and as there are two cylinders to each boring head, and three heads for each point of advance, and never more than three points of advance, we have $1 \times 2 \times 3 \times 3 = 18$ liters required for three headings. With a pressure at the accumulators of from 80 to 100 atmospheres, the pressure at the drills, 6 kilometers distant, is from 60 to 80 atmospheres. The pressure pipe to the drills is 100mm. in diameter, with a shell 4mm. thick, and was tested before installation up to 250 atmospheres. This pipe was supplied by the Mannesmann Tube Works, of Remscheid, Germany.

In the same room with the pumps are two air compressors. One of these is a duplex Burckhardt compressor, with a capacity of 2 cubic m. of free air per minute, built by the Maschinenfabrik Burckhardt, of Basle, Switzerland; and the other is an Ingersoll-Sargent compressor, with a capacity of 3 cubic m. of free air per minute, built by the Ingersoll-Sargent Rock Drill Company, of New York City. These two compressors pump to a receiver consisting of Mannesmann tubes in rows, inclined in the form of a V above a cement-lined pit to allow of their drainage. The pressure carried is from 70 to 80 atmospheres per square cm. From the receiver the air is piped to various points about the works, and into the tunnel to about the fifth kilometer, to supply the compressed-air locomotives.

Besides the three water wheels in the main power house, the

water-power described supplies two turbines in the ventilator house and one in the lighting plant. The maximum power supplied, and its distribution, is about as follows: For high-pressure pumps, 700 h.-p.; for air compressors, 400 h.-p.; for ventilation, 500 h.-p.; for illumination, 100 h.-p.; for shop machines, 100 h.-p.; total, 1,800 h.-p. It is expected that as the work progresses another large turbine and additional high-pressure pumps will be installed.

Besides the hydraulic power plant described above, there is

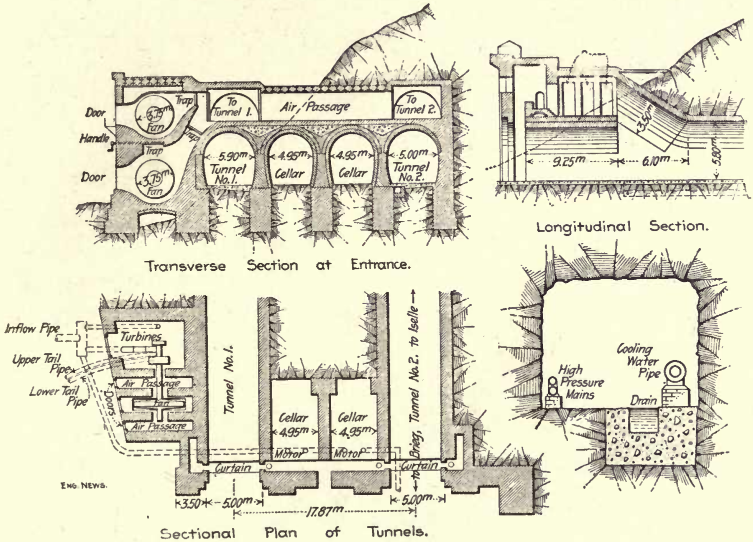


FIG. 120.—Ventilating Plant at Swiss End of Tunnel, and Section of Tunnel Showing Water-pipes.

at the Italian end a supplementary steam-power plant available as a reserve source of power. This plant is located in a building joining the main power house, and consists of three compound engines, two of 80 h.-p. each and one of 60 h.-p. The engine and boiler in each case are combined on a single bed plate. These machines were transported to the works over the highroads, using 40 and 50 horse teams.

Ventilation.—For ventilating the tunnel during construction, and after it is put in operation, a permanent ventilating plant has been installed at each end, as shown in Fig. 120. The

ventilating machinery at each end consists of two 200 h.-p. turbines, running at 400 revolutions per minute, and driving two fans 3.75m. (12.3 feet) in diameter. The turbines were supplied by Escher, Wyss & Co., and the fans by Sulzer Bros.,

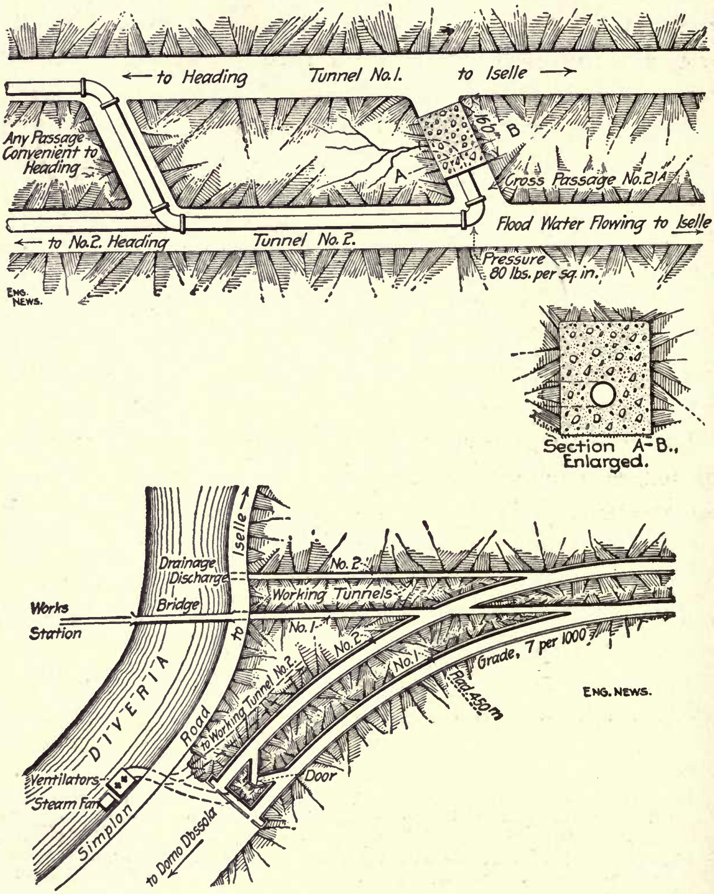


FIG. 121.—Sketch-plan Showing Passages for Delivering Air from Fans to Tunnel, at the Italian End.

of Winterthur. This machinery is arranged differently at the two ends. At the Swiss end the fans are placed one above the other, close to the portal, and the air passage is carried across the roof of the tunnel. At the Italian end of the tunnel the

fans are arranged one behind the other, and some distance away in a ventilator house, from which an air passage leads to the tunnel, as shown in Fig. 121. The ventilators at each end will furnish 50 cubic m. of air per second, at a gage pressure of 250mm. of water, when running in parallel; and 25 cubic m. of air at a pressure of 500mm. of water, when running in series in a tunnel 10 kilometers long and 8 square m. sectional area.

Turning to Fig. 121, it will be seen that the air passage from the ventilator house bifurcates near its tunnel end, and one fork goes to each tunnel. A door at the angle of the bifurcation closes either fork of the passage at will. Sail-cloth curtains close the portals of the tunnel, and are operated either by hand or by electric motors. It will readily be seen from the plans that the air can be circulated either in Tunnel 1 or Tunnel 2, as desired; its movement being accomplished either by compression or aspiration.

The foregoing remarks have referred to the ventilation of the tunnel after completion. To ventilate the workings during construction there is a branch from the air passage (Fig. 121) to the service gallery, opened up along the line of Tunnel 2. If the ventilation is by compression, the air passes along Gallery 2 to the last cross-passage, through this, and then along Tunnel 1, as shown by the arrows in the sketch (Fig. 122). If the ventilation is by aspiration, then, of course, the flow of the air tunnel is in the opposite direction.

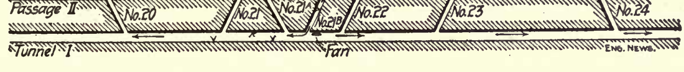


Fig. 122.—Diagram Showing Circulation of Air in Tunnel.

At this point it may be well to note, in explanation of Fig. 122, that it shows diagrammatically the condition of work from the Italian end in July, 1902. At this time the working face of Tunnel 1 was some 500m. (1,640 feet) ahead of

that of Tunnel 2, owing to the fact that work had been stopped in the latter passage by treacherous material at meter 4490. To pass this material, side passage No. 22 had been bored, and excavation from it back to the treacherous material had been begun. This work will again be referred to in more detail; but its importance at this point lies in the fact that it interrupted the route of air circulation described above. Consequently, a small fan was placed at cross-passage 21 B, and forced air through a 14-inch pipe to the working force of Tunnel 1. In conclusion, it should perhaps be noted that all side passages are sealed up as the work advances, to prevent short-circuiting of the air current.

At present the ventilating potential of the plant is much in excess of the actual needs. One fan operating so as to give a gage pressure of 60mm. of water, gives 1 cubic m. of fresh air per second at the working face. This circulation causes no unpleasant draft; but by increasing the gage pressure to 100mm. of water, the miners' lamps used by the workmen are blown out. The turbines and fans are worked alternately, and twelve hours each. It is customary to lay the dust and to refreshen the air entering the fans by occasionally flooding the sides of the passages with water. The penstock for the ventilator turbines is a branch from the main penstock near the two-deck service bridges, previously mentioned.

Previous to the installation of the hydraulic plant, a steam ventilating plant was installed at a point near the main ventilator house. This consisted of a 10 h.-p. engine running a fan delivering air through Tunnel 2, by a pipe 50cm. in diameter. At 1,200 revolutions per minute this fan furnishes 2 cubic m. of air per second, with a gage pressure of 10mm. of water. In case of accident to the main plant, this small steam plant would supply enough air to prevent the stoppage of work, and it is consequently kept in readiness as a reserve plant for ventilation.

Air Refrigeration.—Before commencing the work, the elevation of temperature due to the heat of the rock was estimated as 1° Cent. for every 44m. (144 feet) of subterranean advance;

but the actual temperatures encountered, owing to different influences, have differed materially from those estimated. At the Italian side the great flood of water coming into the tunnel was at first sufficient to keep the air cool; but as the work progressed beyond the leaks it became necessary to resort to artificial means for cooling the workings. At the Swiss side, on the contrary, it has been from the first a matter of some difficulty to keep the air cool enough for comfort, since the infiltration of water has been too small to have any appreciable effect. It should be emphasized, however, that the excessive temperatures which have been frequently recorded in the newspapers have no substance in fact. The highest temperature which has been encountered in the tunnel workings is 55° Cent., and was encountered during the autumn of 1902, at about the eighth kilometer from the Swiss end. As work progresses the temperature appears to be gradually decreasing.

The method of refrigerating the air is practically the same at both ends; cold water is forced into the headings and there broken into spray. At the Swiss end the refrigerating water is pumped from the River Rhône and forced through a 10-inch pipe laid along one side of Tunnel No. 2. This pipe is insulated by jacketing it with a pipe $15\frac{3}{4}$ inches in diameter and filling the annular space with charcoal. With this insulation the rise in temperature due to the passage of water through 9 kilometers of pipe is only 3°C. In Fig. 120 is shown a transverse section of Tunnel No. 2, with the location of the refrigerating water pipe and also that of the high-pressure pipes supplying water to the rotary drills. At the Italian end the cooling water is taken from one of the springs encountered in the tunnel, as shown in Fig. 121.

Illumination.—For lighting the interior of the tunnel gas is used at the north end, while at the south end, far from any gas works, each miner carries his own oil lamp. To the American engineer this crude method of lighting is a matter of some surprise, considering the necessity for ventilation and the fact that there is an electric light plant at each end for lighting the buildings and yards. At the Italian end the central station is

located near the main power house. There are here two generators, one supplying power to 32 500-candle-power arc lamps for lighting the yards, and one supplying 300 incandescent lamps of 10, 16 and 32-candle-power. These generators were supplied by J. J. Rieter & Co., of Winterthur, Switzerland, and are run by a 110 horse-power turbine supplied by the Société de Constructions Mécaniques, of Vevay, Switzerland. There is also a reserve dynamo operated by shafting from the reserve steam-power plant previously described. This is a 16-kw. dynamo, supplied by the Compagnie de l'Industrie Eléctrique, of Secheron, near Geneva, and it supplies ten 500-candle-power arc lamps and 100 16-candle-power incandescent lamps.

Drainage.—The drainage of the tunnel works is effected by gravity, excepting for a length of 500m. in the center of the tunnel. At the Swiss end the fall is 0.2% for 9,184m., and at the Italian end it is 0.7% for 10,086m. The flow of water measured at the Swiss end at the last of October, 1902, was only 2,400 liters per minute, and at the Italian end it was 62,940 liters per minute, with a temperature in summer of 12°C. At the Swiss end the water passes into a special drain excavated in the floor of Tunnel 2, but at the Italian end the whole floor of this passageway is submerged by the flood of outgoing water. Without this auxiliary passage having been excavated, construction at the Italian end would have been very difficult, if not impossible. Indeed, the engineers of this end of the work are frank in stating that they consider that for any mountain tunnel of importance, say over six miles in length, this method of parallel tunnel construction is advisable for several reasons.

Almost all of the water at the Italian end is encountered between meters 4000 and 4600. In this distance several fissures discharge streams varying from 5 liters per second to 425 liters per second. The largest of these is an upright elliptical fissure about 4 feet above the floor of the cross-passage 21 B, Fig. 122, and the amount of flow from it is 13,500 liters per minute.

Workshops.—The main machine shops for the repairs of rock

drills and other machines requiring accurate work are built in line with and adjoining the power station. The machine-tool equipment consists of 7 lathes, 7 milling machines, 3 drills, 2 cold metal saws, 2 screw milling machines, and a planer, a punch and a plate shear, all operated by a small turbine with a small stationary steam engine held in reserve. In addition to these general tools, one end of the shop is equipped with two testing stalls for the Brandt rotary drills employed in the tunnel. In these stalls the drills are mounted and tested on blocks of rock.

Detached from the main building are a number of smaller shops for various purposes. The first of these is used for erecting the heavy steel and timber bracing frames employed in certain portions of the tunnel, as will be described in a succeeding division. A woodworking and carpenter shop adjoins the frame erecting shop, the principal work done here consisting of repairs to the wooden spoil cars. The iron cars are also patched up here. Nearby is a locomotive roundhouse with stalls for four engines, track pits, filters, benches, etc.

Further down the valley are sawmills and an extensive lumber yard. Here the dressed timber for special tunnel timbering is cut and stored. The consumption of wood in the tunnel is very great, and the logs from which it is cut are felled in the forests which cover the precipitous mountain sides above Iselle and transported to the sawmills by an aerial ropeway. The waste timber from the working is used for fuel. Near the lumber yard there is a storage yard for the cut stone for the tunnel lining, and concrete blocks for the same purpose are made in a building located on the opposite bank of the river, at the foot of the spoil bank of rock taken from the tunnel. The concrete blocks are, however, employed only in special cases, as their manufacture is more costly than the production of cut stone, the rough blocks for which are received from the spoil bank or from the quarries near Iselle, to which a track is built.

One of the most important buildings of the plant is the foundry and blacksmith shop. The foundry is equipped for founding the iron and bronze parts of the rock drills and such other small

castings as are required in case of emergency. At the blacksmith shop the cutter heads and hand drills are sharpened at the rate of several thousand a day.

Buildings and Accessories.—Besides the mechanical plant so far described, there are a number of minor structures which are deserving of mention. These will be briefly described without particular regard to location and importance. To supply pure water to the offices, workmen's dwellings and other places where potable water is required, there are two filters, the smaller of which is held in reserve for emergencies. The larger or main filter is built of reinforced cement and is roofed over. It is 10.8m. (35.4 feet) long, 5.3m. (17.4 feet) wide, and 3.6m. (11.8 feet) deep, with a bed formed of gravel and superimposed layers of clean washed sand.

There are bath houses for the workmen and engineers. That for the workmen is a building 37m. (121.4 feet) long and 13m. (42.6 feet) wide; here the men leave their home attire, and can also bathe before changing into it from their working clothes. The soiled working clothes are stored in a special drying room equipped with numerous cords carried over pulleys; these have at one end metal hooks and soap dish; the soiled garments are hung to these hooks and hauled up to the ceiling to dry. Each workman has his individual cord. The bridge leading to these workings is roofed over and boarded in to prevent a too brusque transition from the heat of the tunnel to the cold outside air. The workmen's bath rooms, 80 in number, are lighted by electricity and kept at a constant temperature of 22°C. by steam pipes. The engineers' bath-house has about a dozen rooms with tub and shower baths.

Behind the baths are situated the two hot-water boilers. Here, too, are the laundries, fitted up with large barrel washing machines, centrifugal wringers, etc. These handle only the linen of the engineers and higher employes; the miners generally live with their families and have their work done at home. In the power-house there is a small Linde ice-making plant. A number of habitations for workmen have been erected on the works, but the greater number of these prefer to live in vil-

lages which have sprung up about Iselle and at the bottom of the Tasquera cliffs.

Owing to the rigid discipline enforced and to the natural prudence of the Italian workman, accidents are remarkably few. Full provision is, however, made at both ends of the tunnel to care for accidents. At the Italian end urgent cases and minor injuries are treated in a free dispensary located just at the entrance to the tunnel bridge, and where a surgeon and attendant are always stationed. The more serious accidents are treated in a hospital provided with 40 beds and in charge of a physician and two assistants. Here the miner pays 30 cents a day for the care which he receives. The miners are all insured by the company. The married engineers live with their families. A large boarding house with clubrooms and reading-rooms is provided for the unmarried engineers. Near this clubhouse is a large three-story building used for the constructors' offices, and higher up the valley, near the ventilator house, is the two-story office-building of the Jura-Simplon Railway. Herr Brandau, who directs the work at the Italian end, has a villa on the hillside above Iselle village. There are also a bonded storehouse and lodgings for customs guards and the police provided by the Italian Government.

Transportation Service.—The transportation service is naturally one of the most important services connected with the tunnel work. The motive power used consists at both ends of steam locomotives, compressed-air locomotives and horses. The steam locomotives, of which four are employed at each end, are small six-wheeled four-coupled engines, with $24\frac{3}{8}$-inch drivers and $10 \times 11\frac{3}{4}$-inch cylinders, carrying about 12 tons on drivers. The smokestack is hinged, and the engine has no steam dome. The fuel burned is mixed coal and coke and is practically smokeless. Three compressed-air locomotives are also employed at each end of the tunnel. These have 27 tubular reservoirs, with a capacity of 2,000 liters, carrying a pressure of 70 atmospheres per square centimeter, which is reduced to 15 atmospheres before entering the cylinder. The single cylinder, 125×150mm., is placed horizontally between the frames

and drives the forward axle through gearing with a reduction of 1 to 3.25. The driving wheels are 620mm. in diameter, and the total weight available for adhesion is 6,500 kgs. To replenish the hot-water reservoir there is a steam boiler in the tunnel or hose connection is made with one of the steam locomotive boilers. All steam and air locomotives were furnished by the Locomotiven Maschinenfabrik, of Winterthur, Switzerland.

The service railway has a gage of 80cm., with rails weighing 15 kgs. and 20 kgs. per meter laid on pressed-steel ties. There are three types of spoil cars: narrow ones of wood 1.4m. (4.6 feet) wide, for the buildings, worked by horses; large dump and flat cars for masonry. The dump and flat cars are 1.8m. (5.9 feet) wide, and the dump cars have a capacity of 1.6 cu. m. These cars are run in trains of from 4 to 14 cars, according to the needs of the work. They were furnished by Arthur Koppel, of Bochteim, Germany. The passenger cars are mounted on spiral springs and carry 24 men each; they are run in trains of 18 cars.

At the Italian end of the tunnel the transportation service is through Tunnel 1, since Tunnel 2 is occupied for the drainage of the tunnel. The steam locomotives work up to 4,400m. (14,435 feet) and from this point the air locomotives work to within 300m. or 400m. (984 feet to 1,317 feet) of the heading. This remaining distance to the heading is served by horses, of which there are eight employed. At the Swiss end of the tunnel the haulage is by the main tunnel part of the distance, and then by the side tunnel, the last few hundred feet being served by horses. At the Italian end there are from 26 to 32 trains daily operated on a regular time schedule.

Methods of Construction.—To understand clearly the details of the methods of construction, some further account of the tunnel structure is necessary. The structure extends from a place called Baffi, a few miles from Brieg on the River Rhône, to a point near the village of Iselle, in Italy. The distance between portals is 19,729m. (12.4 miles). The alignment is straight, except for a short curve at each end. The curve at the

Swiss end turns to the northwest and has a radius of 250m. (820 feet), or is a 7° curve, and that at the Italian end turns

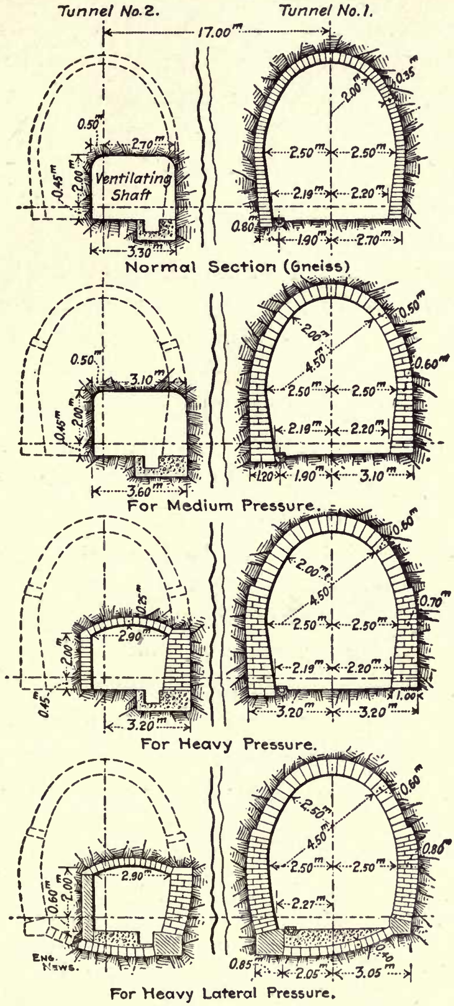


FIG. 123.—Simplon Tunnel: Standard Sections in Various Kinds of Material.

to the east and has a radius of 450m. (1,476 feet), or is a 3° 53′ curve. The elevation of the Swiss portal is 2,250 feet, and

that of the Italian portal is 2,076 feet above the sea. The highest point of the tunnel is a level stretch of 500m. (1,640 feet) at an elevation of 2,310 feet, located about midway between portals. From this summit level the line descends on a 0.2% grade to Brieg and on a 0.7% grade to Iselle. These are the longitudinal characteristics of the tunnel.

Transversally the tunnel consists of twin single-track tunnels exactly parallel in plan and profile. These parallel tunnels are spaced 17m. (55.76 feet) apart, c. to c., and are planned to be identical in sectional profile. The adopted profiles for the different materials are shown by the drawings in Fig. 123. At the summit level the cross-section is increased in dimensions to accommodate two tracks. At present only one of the twin

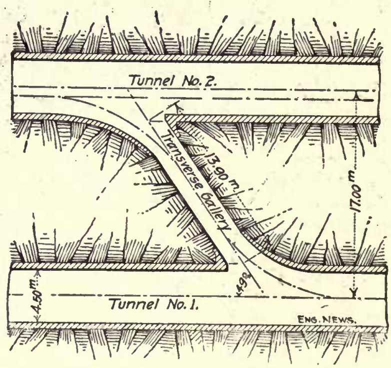


FIG. 124.—Plan of Portion of Twin Tunnels, Showing Cross-gallery.

tunnels is being constructed to its full dimensions; the other is being opened by a small gallery which serves for drainage, ventilation and other services connected with the tunnel work. These characteristics are clearly indicated by the drawings of Fig. 123. At intervals of about 200m. (656 feet) the service gallery and the tunnel are connected by transverse galleries, as shown by the partial plan, Fig. 124. The uniform distance apart of these cross-galleries has been interfered with at a few points where special conditions demanded changes in the adopted plans, but normally they were constructed as shown by Fig. 124 and were spaced 200m. apart.

The tunnel is lined throughout with masonry, the cross-section of the lining masonry varying with the character of the material penetrated, as shown by Fig. 123. The normal section of the lining is interrupted at intervals by niches and side chambers. These are of three forms, as shown in Fig. 125. At every 100th meter there is a small refuge niche of the construction shown by *a*; at every kilometer (0.62 mile) there is a small chamber constructed as shown at *b*, and every four or

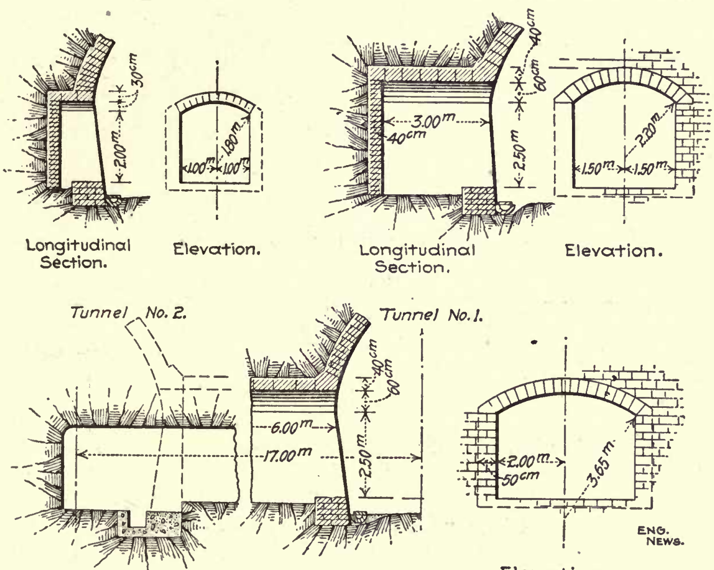


FIG. 125.—Details: a = small refuge niches; b = small chamber; c = lateral chamber and elevation.

five kilometers there is a large chamber constructed as shown at *c*. It will be observed that these large chambers are designed to penetrate from tunnel to tunnel, when the second tunnel is developed to its full section. In conclusion it should perhaps be noted that the tunnel masonry terminates at each end in a portal of architectural design.

Alignment.—To describe in detail the method of fixing the center line of the Simplon tunnel would involve a description of special surveying operations which would run into great

length, and we shall, therefore, simply outline the general plan of operations. These comprised the usual location of the surface axis and terminals and the establishing of reference points from which the axis could be transferred underground, and also the usual periodical surveys by which the underground workings were directed. A preliminary surface survey of the tunnel line was made in 1898, and in 1899 the line was finally and carefully located by a system of triangulation connecting onto the main Swiss triangulation system. This survey gave the engineers the necessary reference points at each end of the tunnel from which the surface axis could be carried underground. The daily direction of the work underground involved no unusual features. A verification of the underground

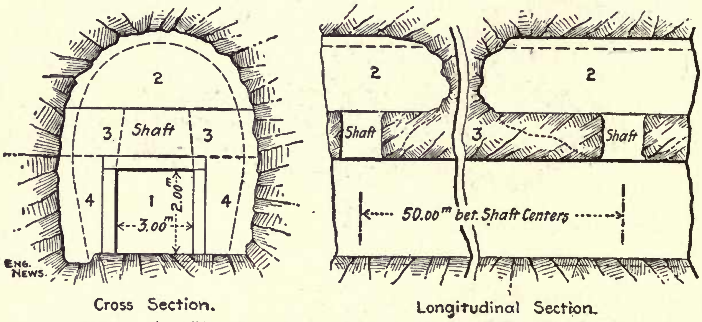


FIG. 126.—Simplon Tunnel: Sequence of Excavation.

line is made each month, every three months and once a year, using separate sets of instruments for each of the surveys. The quarterly verifications are made with particular care, and at the time of the annual verification, which is made on December 4, or the anniversary of Santa Barbara, all work is stopped and the tunnel is cleared and specially ventilated for the surveying operations. The fixed points in the tunnel are located every 100m. (328 feet), or 200m. (656 feet), and are marked during surveying operations by acetylene lamps.

Normal Methods of Excavation.—The methods adopted for excavating the Simplon tunnel can be divided into (1) the method normally followed, and (2) a modification of this

method, which is employed on certain difficult sections of the work. It may be premised further that the specific methods described are those followed at the Italian end of the work. The work at the Swiss end is, however, carried on in a much similar manner.

Sequence of Excavation.—The sequence of excavation followed in taking out the tunnel section is shown diagrammatically by Fig. 126. The center bottom drift is first driven by means of power drills and is then timbered and covered with a closely boarded roof. From this drift a shaft is driven upward

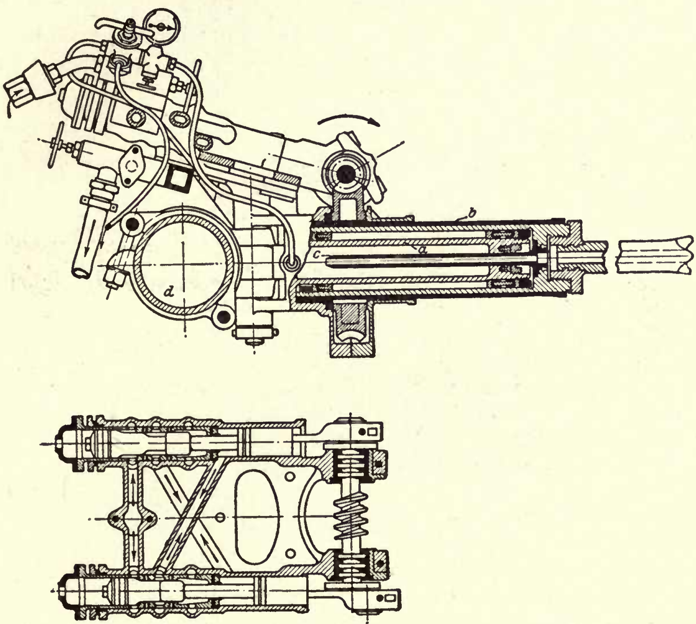


FIG. 127.—Sections Showing Construction of Brandt Rotary Drift.

to the roof line every 50m. (164 feet). The top heading No. 2 is then excavated by working in both directions from each of these shafts. Next in order is the removal of the shallow transverse section No. 3 and then the two side cheeks No. 4. It will be observed that no disturbance of the timbered drift No. 1 occurs during the excavation of parts No. 2 and No. 3, so that traffic through the drift goes on uninterruptedly.

Power Drilling Operations.—The advance drift No. 1 is the only part of the excavation performed by power drills. The drills employed are Brandt rotary drills, the construction and mounting of which are shown by Figs. 127 and 128. The feed of the rotary cutting tool is accomplished by the direct pressure of water in a large cylinder, the piston of which returns automatically when the water supply is cut off. The mandril carrying the boring bar and also the cutter are driven by means of two cylinders located above the feed cylinder. These cylinders

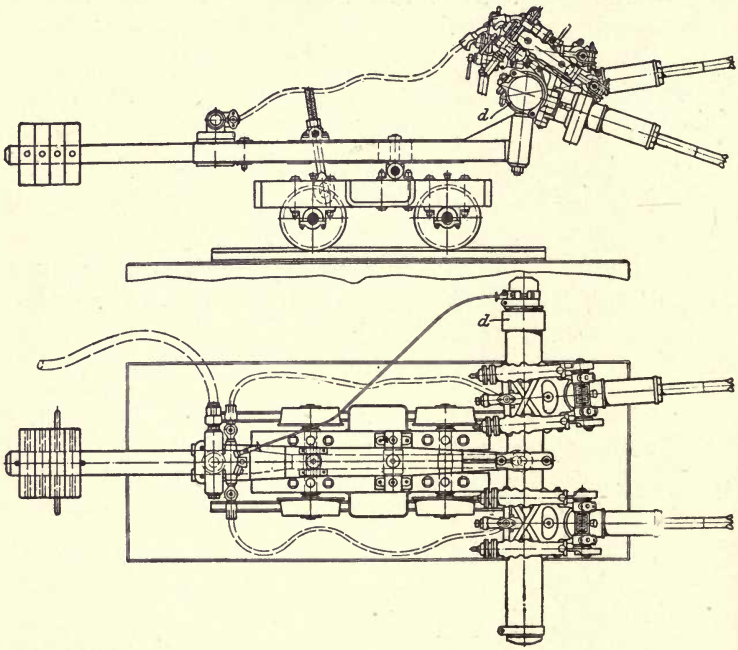


FIG. 128.—Brandt Drill, Mounted for Operation.

operate a shaft having a worm gear which meshes with a worm wheel centered on the mandril. The cylinders are $1\frac{7}{8}$ inches in diameter and their pistons have a stroke of $2\frac{3}{8}$ inches. They are operated by hydraulic pressure and each uses normally 1 liter of water per second. The two cylinders are connected by cross waterways and the piston of one acts as the valve of the other. The speed of the cutter necessarily varies for different

densities of rock, but its highest speed is ten revolutions per minute. The drill as described is mounted in groups of two or more on a heavy iron thrust-bar about 12 inches in diameter. This thrust-bar is pivoted to the drill carriage and is counterbalanced, as shown in Fig. 128. It will be clear, of course, that all holes bored by the drill must radiate in direction from the transverse thrust-bar as an axis.

In the Simplon tunnel work the drills are mounted in groups of three, and one carriage is worked in each heading. Normally there are two headings in progress, namely, the advance drift No. 1 in the tunnel, and the service gallery. At times two headings have been worked in the tunnel, making three sets of drills and nine boring heads in operation. The hollow head or cutter is 3 inches in outside diameter and has a bore $1\frac{1}{2}$ inches in diameter. The depth of the hole bored is usually $4\frac{1}{2}$ feet, and different lengths of boring bars are employed to suit the more or less worn-up condition of the cutter head. This is attached to the boring bar by a one-quarter turn of a square quadruple threaded screw. The number of square heads employed is considerable, there being 24 allotted to the Italian end of the work.

In normal operation the work proceeds as follows: The thrust beam is wedged between the two side walls of the heading by means of timber blocking. The holes are then started by means of a V-shaped center bit, each hole being located with due regard to the rock seams and stratification and so as to obtain the best blasting effect possible. After the holes have been started the center bits are replaced by the rotary cutters. The time taken to bore one hole varies considerably, but it may be estimated from the daily advance made, which is given below. Ordinarily, ten or eleven holes are bored. The section at the heading is nominally $6\frac{1}{2}$ x $9\frac{1}{2}$ feet, or $61\frac{3}{4}$ square feet, and as the depth of each blast is roughly $4\frac{1}{2}$ feet, the cubic contents removed with each blast is from 265 to 275 feet. During the early stages of the work, and again recently, the number of blasts amounted to only four or five per day, and the average daily advance for the month was about 16 feet at the Italian end, and

from 20 to 21 feet at the Swiss end. This work was in a gneiss rock. In rock of a more friable nature, such as the anhydrite or lime sulphate, an advance of as much as 34 feet has been made in 24 hours. After each blast the time required to clear the heading, set the drills, complete the boring and remove the drill carriage to a point of safety is upward of an hour.

The cutter is aided in its work by the water discharged into its interior from the cylinders. This water emerges from the drill hole around the outside of the cutter and carries with it the borings in the form of a coarse powder. The cutter teeth are set with a clearance of about ¼-inch, so that the hole bored is 3½ inches in diameter or ½-inch larger than the cutter cylinder. This amount of clearance is ample to keep the cutter from binding and to permit the drill hole to be readily freed from all borings. When desired, the water may be discharged direct from the cylinders without entering the cutter. Except in the very hardest rock no core is formed by the drill.

Explosives.—The explosives used are dynamite at the Italian end and blasting gelatine at the Swiss end. The following are the compositions of these two materials:

	Dynamite.	Gelatine.
Nitroglycerine	83%	64%
Octomitric cotton	5%	3%
Potassium nitrate	10%	—
Cellulose	2%	8%
Soda nitrate	—	24%
Carbonate of magnesia	—	1%
Total	100%	100%

At the Italian end the dynamite storage house is located at Varzo, about one and one-half miles from the tunnel portal, and each day's supply is taken from here and transported on a push car to a storehouse located in one of the cross-galleries of the workings.

Mining Operations.—The dynamite is put up in $\frac{1}{2}$-kg. (1 lb.) packages, and each hole is charged with six packages. Each blast, therefore, represents from 60 to 66 pounds of explosive. The charges are fired by means of ordinary fuses, which are so cut as to give a half minute interval between the firing of successive holes. The blast frequently throws the fragments of rock to some distance, and all machinery which can be removed, as well as the men, takes refuge in the cross-galleries and the service gallery of Tunnel No. 2.

About 10 or 15 minutes are required after each blast to clear the heading of fumes. This is accomplished by means of the ventilating pipe, which runs close up to the face, and by means of a spray operated from the pressure pipes. The ventilating pipe exhausts about 35 cubic feet of air per second, and the spray is particularly useful in absorbing the sulphurous gases.

The spoil from the blast is cleared away from the face by one gang of men, while another loads the collected rock onto narrow-gage cars hauled by horses. No tools are used, all the material being handled by manual labor alone. Every effort is made to rush this work of clearing the heading so that the drills may be got back to work as soon as possible. To this end the clearings gangs are composed of men who have been previously rested by performing light work only, and only the most skilled and energetic laborers are employed. The majority of the laborers are southern Italians, both at the Italian and the Swiss ends. Some Swiss and a few Prussians are employed, but mostly in connection with the machine work. There are 14 or 15 men at each heading and they are worked in three shifts daily. Each gang has two horses for each shift. These are supplied by a local peasant job master at $1.60 per day, and each horse works eight hours a day, with an occasional day's rest. The horses die off quite rapidly, and each death is paid for by the tunnel contractors. Various other methods of transportation have been considered and a few others have been experimented with, but none has appeared to the engineers to offer any economy over horses for transportation in the advance heading. The horses take the cars to compressed-air locomo-

tives and these in turn take them to steam locomotives, as described before.

Timbering.—The timbering of the tunnel excavation comprises, first, the timbering of the bottom advance drift; second, the timbering of the vertical shafts, and, third, the timbering of the top heading and the enlargements. All portions of the work are timbered. The timber ordinarily and generally used for timbering at the Italian end is birch and fir cut from the mountain slopes above Iselle and conveyed to the tunnel entrance by wire ropeways. The amount of timber used is large and a considerable force of lumbermen is kept steadily at work by the contractors.

The timbering of the bottom drift or advance gallery con-

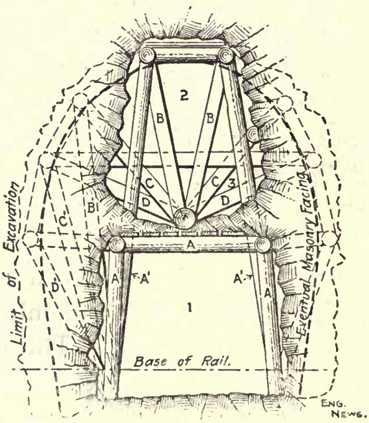


FIG. 129. (1)—Standard Timbering; (2)—Extra Heavy Timbering.

sists of quadrangular frames set at intervals and carrying a longitudinal lagging on their caps. The side posts are sometimes vertical and sometimes have a slight batter, and the frames are with or without sills, according to the transverse lay of the rock seams. The several drawings, Figs. 129-130 inclusive, all indicate quite clearly the nature of the advance gallery timbering. These drawings show various designs of the full section timbering used. The form shown by Fig. 129 (1) is the one preferred when it can be used, but that shown by Fig.

129 (2) is much used, particularly at shafts and where shelling of the roof rock layers is liable to occur. Fig. 130 shows the temporary fan-shaped timbering employed in opening up the roof gallery. Ultimately the radiating struts *B, C* and *D* are replaced by the full section members *A', B', C'* and *D'* as the excavation is developed. In the full section timbering the transverse frames are spaced 8 feet and 10 feet apart and sometimes even greater distances, depending upon the nature of the rock penetrated.

Lining.—The tunnel is lined with coursed masonry from end to end, and the character of the masonry at different points is

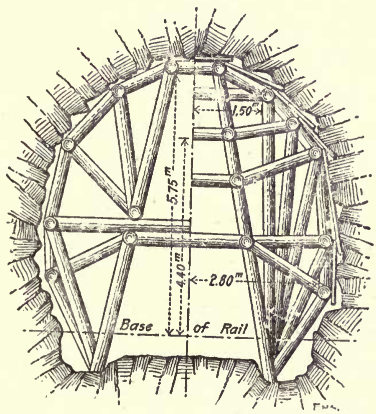


Fig. 130.—Progressive Stages in Arch Timbering During Enlargement.

shown by the standard sections of Fig. 123. Fig. 125 shows the masonry work of the niches and side chambers. The facing stone of all this masonry is antigorio gneiss at the Italian end. Under normal conditions the lining is built as fast as the enlargement of the section is completed, but where water has been encountered, or where the rock is of unstable character, there has often been a distance of 1,300 feet between the completed side walls and the end of the enlarged section, and of 1,600 feet between the latter point and the arch masonry. The endeavor of the engineers is always to keep the lining close up to the enlargement.

The method of constructing the lining is to build the side walls up to the springing lines and then to follow with the roof arch masonry. The walls being built, a vertical frame, composed of a cap, a sill and posts, is set up as close to each as the batter of the walls will allow. These frames are about 10m. (32.8 feet) long and are indicated at *A A* in Fig. 131. Transverse timbers are placed so as to span across the space between these frames and carry a flooring. On this flooring are set the ribs for the arch center. These ribs are composed of two 7-inch I-beams bent edgewise and connected by bolts at the crown.

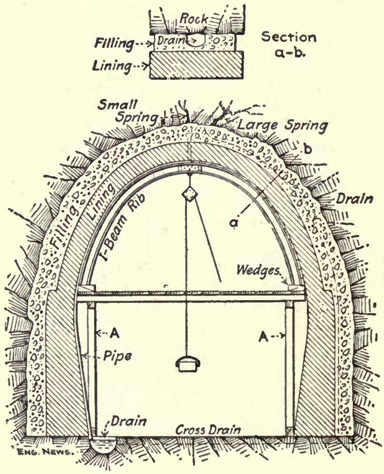


Fig. 131.—Diagram Showing Method of Constructing Lining.

They are adjusted to elevation by means of wedges under their ends, and carry a timber lagging on which the arch masonry rests. As will be seen from Fig. 131, the staging is of such dimensions that the material cars pass freely underneath it, and the arch material is hoisted from these cars to the platform by means of a chain hoist.

Where there is a strong discharge of water from the roof rock it is diverted during the construction of the arch ring by means of metal shields or plates set below the roof poling-boards, and when the ring has been completed and the brick filling is being placed a channel is formed in the latter to take the

water down behind the arch ring and the side wall, to the foot of which is a passage to the main drain formed in the floor of the tunnel at one side. This drainway is formed in hydraulic cement, as indicated by Fig. 131, which shows the spring located on the haunch opposite to the tunnel drain, thus requiring a cross-passage in the tunnel floor. In some instances where there has been a small leak in the roof rock it has been connected with a ½-inch or ¾-inch pipe led down through the filling and arch ring, and then carried down the soffit and side wall.

The thickness of the arch ring varies from 14 inches in solid

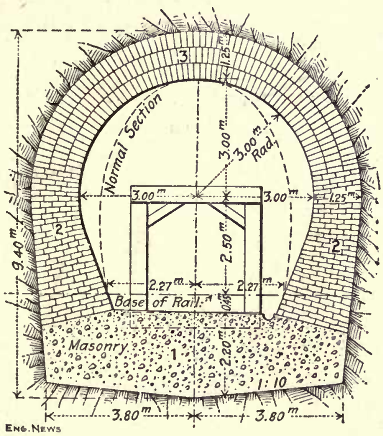


FIG. 132.—Lining Used for Very Heavy Pressures.

rock to 20 inches and 24 inches in friable rock; in exceptional cases, such as are noted further on, the arch ring has been made upward of 4 feet thick. The filling above the arch ring is cemented rubble, and it amounts to about three cubic feet per lineal foot of tunnel.

Materials Penetrated at Italian End.—It will be remembered that the working entrances at the Italian end are on the line of the tunnel tangent extended. The short curve which will form the actual tunnel will be excavated toward the conclusion of the work. Practically this same method of opening up the work is followed at the Swiss end. The materials penetrated, begin-

ning at the working entrances at the Italian end, have been as follows: At the entrance there was a mere crust of ferrous quartz. This was followed for a distance of 4,350m. (14,268 feet) by a very hard gneiss lying in horizontal strata and known as antigorio. This gneiss contained occasional seams of crystalline rock, quartz, sulphur, pyrites, etc. From meter 4350 to meter 4450 the material was calcareous rock and green mottled cipolin. Previous to the ending of the gneiss rock, however, water was encountered as described in the earlier part of this article. Beyond the cipolin for about 40m. (131.2 feet), or from meter 4450 to meter 4490, a disintegrated slate clay was encountered, which proved to be a most treacherous material and which has up to the present time been the most difficult part of the whole tunnel. The method of penetrating this disintegrated rock is described in a succeeding section. Succeeding the disintegrated slate there was about 60m. (196.8 feet) of a jumbled mixture of mica schist, schistic gneiss, cipolin, quartz and white marble. From meter 4550 to meter 4850 the rock was anhydrite or crystalline sulphate of lime. Then followed calcareous rock, schists, anhydrite, granitoid rocks and schistic gneiss, the last being nearly as dense and hard as the antigorio first encountered. All these rocks were in horizontal strata. These conclude the list of materials so far penetrated.

As already described, the method of penetrating the materials described was to open an advance bottom drift by means of power drills, then to project upwards shafts at intervals and to extend a top heading from each of them, and finally to enlarge this heading and open up the full profile. This enlargement was all accomplished by hand drilling and blasting. Normally this method of excavation has proved satisfactory, but when the disintegrated slate was struck it failed entirely, and another and special method had to be devised for carrying on the work. This method will now be described so far as it has been developed.

Methods of Excavating Through Disintegrated Rock.—The disintegrated slate clay was a water-soaked coarse powder abso-

lutely without stability. It was penetrated by first opening a bottom drift and then enlarging this drift and erecting the lining. This was of unusually heavy section, and is shown by Fig. 132. At first it was attempted to proceed by using the ordinary timbering methods with timbers of unusual strength, but the crushing of this timber soon put a stop to the task. First one thing, then another, was tried in the way of special

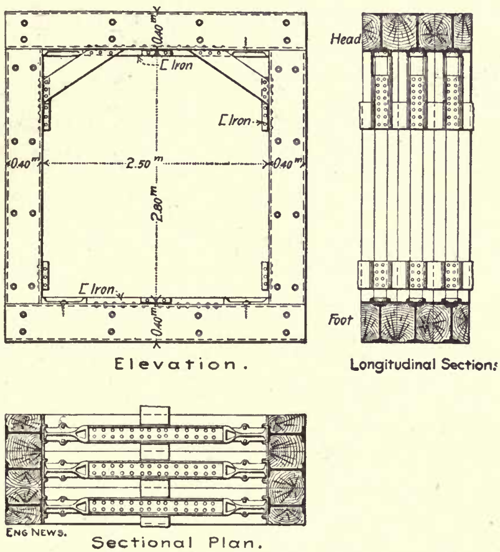


FIG. 133.—I-beam and Timber Lining.

timbering, but all of them failed, and no success was had until a combination method of steel and timber strutting was employed. This is shown in the succeeding illustrations, Figs. 133 to 136.

Advance Drift.—The advance drift was excavated by opening first a 5 x $5\frac{1}{2}$-foot drift near the bottom and timbering it with rectangular frames sheeted with poling-boards on all four sides. This small drift was then enlarged by taking out a heading above it and working down the sides. In the enlarged section a lining composed of special I-beam and timber frames was then placed. Beyond the general statement given it is not possi-

ble to describe the mode of operation. The excavation and timbering was done piecemeal by scraping away a bit at a time and keeping the faces supported by lagging and struts placed as demanded and as would but serve the immediate purpose. The final I-beam and timber lining was erected by first placing the sill, then erecting the cap and finally wedging in the wall

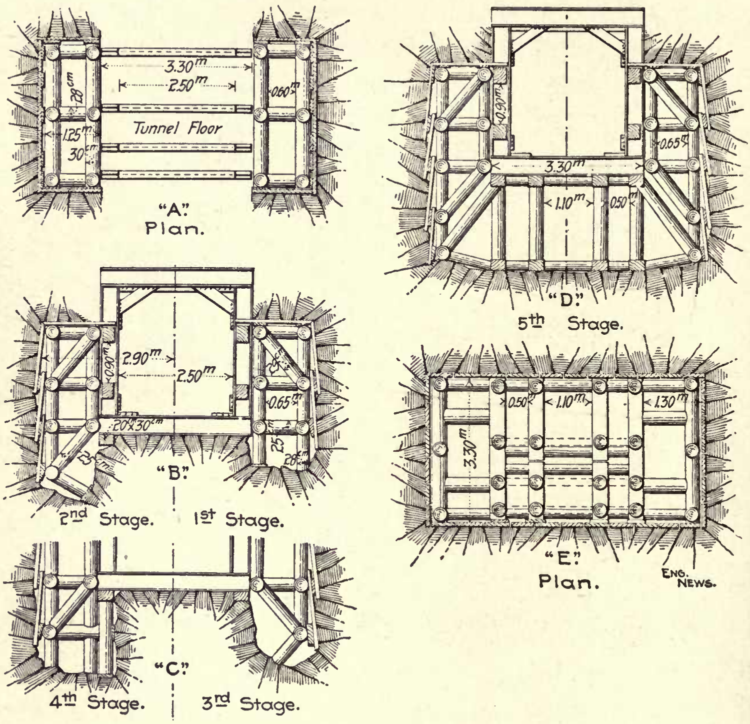


FIG. 134.—Sequence of Operations in Soft Rock.

posts. The construction of these lining frames is shown by Fig. 133. In the most difficult portions the frames are set close together, as illustrated, so as to form a tight lining, but in more stable material they were spaced varying distances apart and filled between with concrete. Each frame weighed 2,640 pounds, and altogether 74 were erected. This work was enormously expensive.

Enlargement of Section.—The method of enlarging the drift which was timbered by the I-beam and timber frames is illustrated by Figs. 134 and 135, inclusive. Work is started by chopping out the timbers between a pair of the steel wall beams at a height convenient for the passage of men and materials, as shown at *B,* Fig. 134. This opening is framed with a square cap and sill and vertical side posts, leaving a clear opening 0.9m. (2.9 feet) high and of a width equal to the distance between the iron frames less the thickness of the side posts. Excavation is begun horizontally outward from each opening until a space 4 feet deep and 4 feet 8 inches high has been excavated and timbered, and sheeted, as shown by Fig. 134, *B,* "first stage." The timbers used are round in cross-section and of the dimensions shown by the drawings in centimeters. This opening is simultaneously carried downward, as shown by the several stages of Fig. 134, *B* and *C,* and laterally until it has a width of about 9 feet 10 inches, as shown by the plan, Fig. 134,

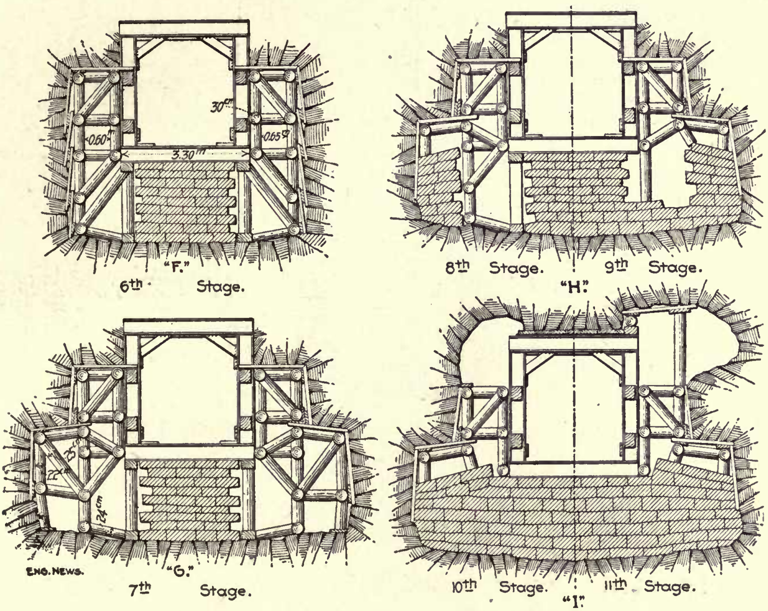


FIG. 135.—Sequence of Operations in Soft Rock.

A. The work is now ready for underpinning the steel frame. The first operation is the insertion of a longitudinal 8 x 12-inch timber under the corners of the frames, as shown in Fig. 134, *B*, "second stage." Under this beam four 12-inch wood posts are inserted in local cavities excavated for them, as shown by Fig. 134, *C*, "fourth stage." These posts stand on a floor plate, as shown in Fig. 134, *D*, "fifth stage," and the whole frame is braced laterally against the wall and floor timbers, as shown.

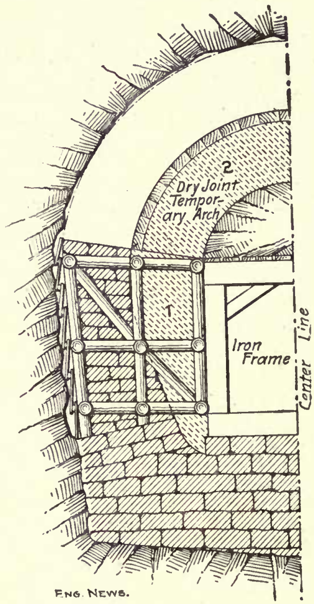


Fig. 136.—Suggested Method for Building Roof Arch Through Soft Rock.

The next operation is to place a second frame of cap, posts and floor plate further under the frames. These operations proceed simultaneously from both sides until the underpinning is completed, as shown by Fig. 134, *D* and *E*.

The next step is to build the center portion of the masonry floor, as shown at Fig. 135, *F*. Lateral extensions of the excavation for the side walls are then made and timbered, as shown by Fig. 135, *G*. Side wall construction is then begun and carried upward, as shown by Fig. 135, *H* and *I*, until the springing

line of the arch is reached. The work described is conducted from a number of openings at once, and these are then connected by breaking down the ends of the section in both directions until the excavations and masonry meet. The method of enlargement for the construction of the roof arch has not been finally worked out, but a plan which has met with favor is to fill in the space 1, Fig. 136, with temporary masonry and then construct the temporary masonry arch 2 as a center upon which to construct the permanent arch.

Waterworks Tunnel at Cincinnati, O.—The new water supply system at Cincinnati, O., includes an intake tunnel with shaft and crib in the Ohio River, and a tunnel four and one-quarter miles long from the intake pumping station and purification plant to the city. The system is designed to supply 60,000,000 gallons per day (for a present population of about 350,000), with provision for an increase to 90,000,000 gallons daily capacity.

The intake tunnel under the river is 7 feet diameter and 1,426 feet long, with a 7-foot intake shaft close to the Kentucky shore, and an 8-foot shaft at the pumping station on the Ohio shore. The tunnel is lined with brick and has a grade of 3 inches in 100 feet from the intake shaft down to the shore shaft. The shore shaft opens into a pump pit 98 feet inside diameter and 85 feet deep. The bottom of the pit is formed by a great timber caisson which was sunk into a firm bed of sand to within about 17 feet of bed rock, and in view of the subsequent troubles it seems strange that it was not carried down to the rock. Early in 1901, two cracks appeared in the shaft masonry, below the caisson, showing that under the head due to high water in the river the water in the sand had forced the floor upwards, the maximum movement being about 5 inches. Investigations showed that the deck bulged up in the middle, there being no movement at the sides; they further showed that the movements were repeated with other stages of high water. A counterbalance weight was built on the center of the deck and this settled the floor back 2½ inches, but did not stop the movements. The driving of tunnels under the caisson and building

a concrete foundation so as to form a solid connection between the caisson and bed rock has been proposed, but is not now considered necessary. The cracks were at first filled up—but afterwards this filling was cut out—all the pumping-engine castings available were placed on the floor, and the pump pit was filled with water. At the present time the caisson has been forced back to within 1-1000 foot of its original level, and it is not anticipated that any further trouble will be caused, especially in view of the great weight of the pumping engines when completed.

Land Tunnel.—The tunnel carrying the treated water to the city is 22,264 feet long from the shaft at the clear-water reser-

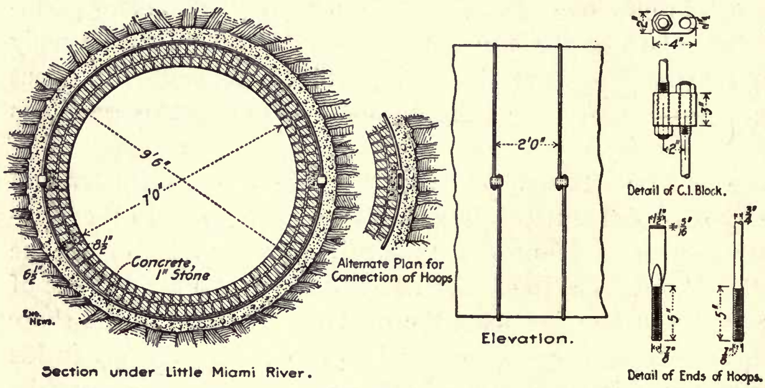


FIG. 137.—Water-works Tunnel: Section of Land-tunnel.

voir to that at the city pumping station. It is approximately parallel with the Ohio River shore line (but from 300 to 900 feet distant) and has a down grade of 1 in 2,000 towards the city. Its top is 60 feet below low-water level, or 130 feet below high-water level in the river, but when in use the inside pressure will be equivalent to 90 feet head. The tunnel, Fig. 137, is 7 feet inside diameter, and lined with two rings of specially made radial pressed vitrified shale brick, laid with close joints; the inner surface is as smooth as the best pressed-brick building work. The bricks are 3 x 4 inches, 9 inches long, with bonding grooves on the sides, and the face curved to a diameter of 7 feet. The brick lining is backed with concrete, the minimum

thickness of concrete being 6 inches. Where the tunnel crosses beneath the Little Miami River, the lining is reinforced by rings of $\frac{3}{4}$-inch round steel bars, 2 feet c. to c., as also shown in Fig. 137. The tunnel is completed, and in order to determine the amount of leakage, if any, it has been filled with water from the city mains. The tunnel was driven through limestone and shale rock, with about 25 feet of rock above the crown. This rock was in some places badly shattered and much water was encountered. The pneumatic or air-lock system was tried for a short distance (350 feet), but did not prove satisfactory. The successful method of dealing with the water consisted in driving pipes into the seams, so as to discharge the water within the tunnel; where the streams were too small and too numerous for this, aprons were put in to collect the water outside of the lining, the apron leading to a single pipe passing through the lining. In this way the brick lining and concrete backing were put in without trouble from washing, and the pipes were left projecting into the tunnel. After the work had set, the pipes were fitted with valves, and then cement grout was forced into them under 80 pounds' pressure; when no more grouting could be pumped in, the valve was closed and the grouting machine transferred to another pipe. The grouting was found to travel considerable distances, sometimes appearing at other pipes beyond where the grout was being forced in. The sealed pipes were left for 10 or 20 days, to insure thorough setting of the grout, and they were then cut off a little back of the tunnel face, and the recess pointed up. In one place there were 300 pipes 1 to 2 inches diameter in 1,000 feet of tunnel. In spite of the seamy rock, with direct connection to the river, and in spite of the amount of water encountered, the finished tunnel is very dry, the measured infiltration being only 10 gallons per minute for the entire length.

Pockets of gas were encountered at several places, and several small explosions occurred; six men were killed by gas explosions. Further trouble was prevented by providing an increase of ventilation from the compressed-air mains which were supplying power for the rock drills. The gas was natural gas,

and this with a little dilution with air is less explosive than marsh gas with much dilution.

The work was prosecuted by ten headings from the two permanent shafts and four intermediate shafts, the latter being afterwards sealed and filled and the tunnel lining carried past them. As the center line of the tunnel makes one or more angles between each pair of shafts, the survey work was somewhat complicated, more especially as buildings and other obstacles prevented direct sights on some of the tangents. The tangents were measured several times at different temperatures and the average distances taken. The angles were also repeated and averaged, each angle being measured no less than ten times and by at least three observers. For the levels, bench marks were established at one-half-mile intervals. The line was transferred down the shafts by two wires, kept taut by 20-pound weights in glass jars filled with glycerine. The wires being adjusted to line by the transit over the shaft, were then used by the tunnel transit to project the line upon scales set 300 feet apart and attached to anchors in the tunnel lining. The levels were transferred down the shafts by measurements with steel tapes, the measurements being repeated and averaged.

The east end shaft is shown in Fig. 138, but in construction the intersection with the opening for the 7-foot nozzle was finished in concrete instead of with a ring of special brick as originally designed. The interior lining, also, instead of being brick on edge, as shown by the drawing, was of special radial or voussoir-shaped brick laid flat. Each brick used is 3 x 4 inches, 9 inches long, with bonding grooves top and bottom, and a face radius of 5 feet. The shaft is 10 feet inside diameter, and the upper part is built within a shell of $\frac{3}{4}$-inch steel plate, 12 feet diameter, extending to the rock and having a water-tight seal. The rings are 6 feet high, with three plates to a ring and 16-inch triple-riveted vertical cover plates. In the lower part the rings are butt-jointed, with inside 6-inch single-riveted cover plates; but at the top the rings are lap-jointed and set alternately inside and outside. The contractors for the tunnel were W. J. Gawne & Co.

Survey Work for the Land Tunnel.—The surveying methods employed for the four and one-quarter mile land tunnel to the city have been described as follows in a paper by Mr. John A. Hiller, Assoc. M. Am. Soc. C.E., who was Resident Engineer during construction:

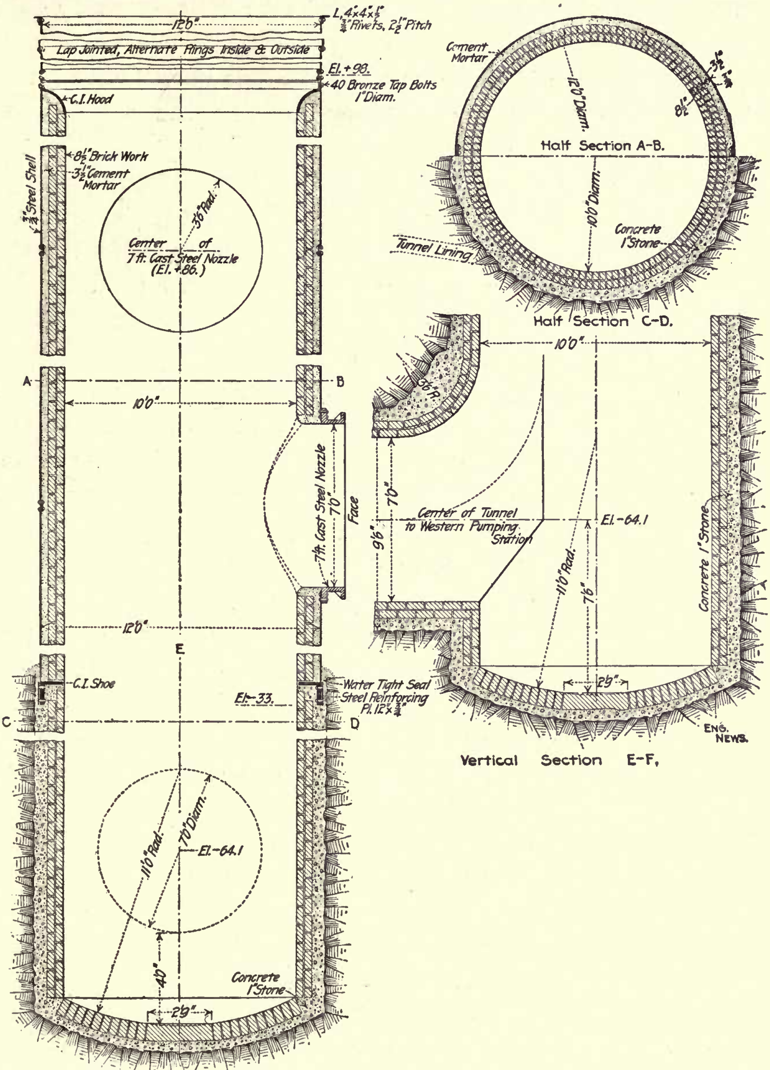


FIG. 138.—Water-works Tunnel, Cincinnati, Ohio: East End Shaft.

"The construction was executed from the permanent shaft at each end and four working shafts, making ten headings. The alignment of the tunnel not being a continuous tangent between the shafts, but being broken by one or two angles between, it became necessary to make a very careful survey of the surface line to establish the true position and magnitude of the angles.

"The centers of the shafts and the angle points were established from the preliminary survey line, then the tangents and angles were measured.

"Between shafts 1 and 2 the line traverses a comparatively thickly built up portion of the city. Tangent 1 passes through a frame dwelling; and to obtain the line between shaft 1 and angle 1, the transit was set up on a chimney of this house, shifted into the line, and from this position permanent points were fixed on both sides and foresights established.

"Tangent 2 passes through the machine shop and retort house of the East End Gas Works, and the office, stable and coke piles of the Marmet Coal Company. With these obstacles on the line, it was found impossible to get the instrument at any point where the two extremities of the tangent could be seen. A transverse line was run, beginning at angle 1, running to angle 2 and returning by another route to angle 1. This was a closed survey, which was divided by tangent 2 into two parts, which, when considered separately, gave tangent 2 as the closing line for each part.

"The results obtained from three trials of this traverse are given in Table 1, each result being the mean found by considering each part:

TABLE 1.—MEASUREMENTS OF TANGENT 2

No. of trial.	*Length of tangent 2.*	*Size of angle 1.*	*Size of angle 2.*
1st	1314.5920	15° 27′ 32.1″	9° 08′ 45.9″
2d	1314.5892	15° 27′ 11.4″	9° 08′ 43.1″
3d	1314.5871	15° 27′ 14.6″	9° 08′ 49.9″
Mean	1314.5895	15° 27′ 19.4″	9° 08′ 46.3″

"On the third tangent there was one building and a pile in a tramway; a perpendicular offset line passed these obstructions.

"The remainder of the tangents offered no obstacles which could not be overcome by the erection of foresights from 10 to 20 feet in height.

"The crossing of the Little Miami River was made by triangulation, using a quadrilateral, one of whose diagonals was the tunnel line.

"The measurement of all tangents was made with a 50-foot steel tape, which was ascertained to be correct at 60° Fahr., with a pull of 14 pounds. Stakes were driven along the line every 50 feet; and at breaks in the ground, the line was marked thereon, levels run to establish the differences of elevation of the stakes, the tape stretched, and the length and the temperature of the air for each length was taken and recorded.

"Each tangent was measured forward and checked backward during the summer, and the whole operation repeated later during the winter. In case of any great difference a check measurement was made. Thus each line was measured at least four times under widely different weather and temperature conditions, with no accepted difference greater than one in about 30,000. A mean of all measurements was taken as the length of the tangents. These mean measurements did not differ more than one in about 50,000 from any extreme.

"The field data were tabulated for reduction to the horizontal distance and to a temperature of 60° Fahr.

"The angles were measured by repeating each ten times, by three or more observers, and the average result of all observations was accepted as the most probable.

"The bench levels were run from an established bench at California to near shaft 1 and return. Benches were established about every half mile, and in the immediate vicinity of the shafts. Such parts of the line where the differences of the two runs were greatest, a check run was made and the mean differences of elevations used to determine the elevations of the benches.

"**Transfer of the Alignment into the Tunnel.**—At each shaft an observation station was erected for each tangent and foresights built at or near the distant angle points. These stations were

so built that the observer's platform was independent of the transit support, and all enclosed in a small house to protect the instrument from sun and wind. The wires used for plumbing down the shafts were No. 5 piano wire, about one-sixtieth of an inch in diameter, held in a clamp at the top of the shaft in such a manner that the wire could be moved tranversely by a slow-motion screw. The method of securing the device to top of the shaft cannot well be shown, as the local conditions at each shaft required a different arrangement. At the lower end of the wire was a hook, upon which was hung a cylindrical lead weight of 20 pounds. The weights were suspended in glass jars containing glycerine. This arrangement permitted the weights being seen at all times and afforded absolute assurance that the weights hung free. Back of each wire was a small shield or background painted white; the lower end of the wires being blackened, showed distinctly against the white ground. The jar nearer the tunnel transit was supported on a small stand about 3 feet from the floor; the farther jar rested directly upon the floor of the tunnel. This permitted each wire being viewed separately and allowed no chance or confusion of viewing the wrong wire. An electric light was supported so as to throw light upon the wire and background.

"The tunnel transit was supported on a wooden strut secured against the tunnel arching by four large set-screws. A tripod could not be used on account of the wooden floor being too springy for a secure set-up.

"The tunnel transit was provided with a slow-motion arrangement whereby the whole transit could be moved a small distance at right angles to the tunnel line, allowing of very small changes in the position of the instrument.

"The cross-hairs of the transit consisted of a diagonal cross and two vertical hairs, so spaced that they covered about one-sixteenth of an inch at a distance of about 60 feet. This made the sighting of the instrument very exact, as the cross-hairs and the plumb wire appeared white between, about equal to the diameter of the wire.

TABLE 2.—DATA OF TUNNEL MEASUREMENTS.

Shaft.	*Heading.*	*Date of beginning of excavation.*	*Date of meeting of headings.*	*Distances between wires.*	*Length driven.*	*Error in alignment.*	*Error of levels.*	*Angles turned in each heading.*
1	1	Dec. 26, 1900		9 ft. 3 in.	478.3 ft.			0
			Jan. 16, 1903			1-16-in.	¼-in.	
6	10	July 25, 1902		8 ft. 0 in.	541.3 ft.			0
6	9	July 25, 1902		8 ft. 0 in.	641.1 ft.			0
			Oct. 17, 1903			⅞-in.	⅝-in.	
2	2	Dec. 21, 1900		6 ft. 0 in.	3,220.2 ft.			2
2	3	Dec. 21, 1900		6 ft. 0 in.	3,443.0 ft.			2
			Oct. 28, 1903			⅜-in.	1 ⅝-in.	
3	4	May 11, 1901		8 ft. 0 in.	2,267.9 ft.			0
3	5	May 11, 1901		8 ft. 0 in.	2,686.7 ft.			2
			Jan. 20, 1903			5-16-in.	1 ¼-in.	
4	6	June 5, 1901		6 ft. 6 in.	2,472.1 ft.			0
4	7	June 5, 1901		6 ft. 6 in.	3,507.1 ft.			1
			Aug. 4, 1903			1 ½-in.	¾-in.	
5	8	Dec. 1, 1901		9 ft. 3 in.	3,006.4 ft.			0

"The operation of transferring the line into the tunnel consisted of setting a transit, in the observation station, on line by double foresights and bringing both wires to this line by means of the slow-motion clamps. The tunnel transit was then brought into the line of the two wires and the line transferred to the scales, fastened to anchors in the masonry lining of the tunnel,

The scales were placed about 300 feet apart and read by verniers to 0.01 inch.

"All necessary reversions of the transit were made to eliminate all probable errors of instrumental adjustment. Readings were made on the two scales and recorded for each position of the transit. Several independent trials were made, and in all about 50 readings were taken on each side, in each heading, and a mean accepted as the working base line inside the tunnel. This line was extended into the tunnel as the excavations were advanced, always making the necessary reversions of the instrument and accepting the mean of all trials as the correct line.

"The required distances from the shafts to the angle points were measured along the roof, using the same precautions as in the measurement of the surface line. The angles were turned by repeating several times. Afterward curves of 30-foot radius were used for easing off the intersections. The angles being generally small, none of these curves was long, and little or no additional excavation was needed in order to place the lining on the curved line.

"The levels were transferred into the tunnel by steel-tape measurements down the shafts. Four to eight trials were made at each shaft and a mean result accepted.

"Table 2 shows the distances between the wires at each shaft, the lengths driven in each heading, and the errors for closing for each meeting point.

"The engineering department took samples of air from each heading daily and made tests for explosive gas. The daily progress of each kind of work in each heading was measured and recorded on a progress diagram. Samples were taken from each shipment of cement and tests made for soundness and tensile strength.

"Lines and levels were given in each heading for every advance of about 100 feet. Holes were drilled in the roof about every 30 feet and plugs driven, containing a small staple in the true line. The distances from the plug to the axis of the tunnel were computed and a list given to the heading foreman for his guidance in pointing the holes when drilling. These same

grades were afterwards used when setting invert forms. The spring-line grades were marked on the invert for setting the arch centers."

Telephone and Freight Transportation Tunnels at Chicago.—A peculiar system of tunnels exists at Chicago, consisting of a network of small tunnels under the streets (and including nearly all the principal streets in the downtown districts). These tunnels carry telephone and telegraph cables, but are also to be operated for the transportation of mails and freight, connecting the several postoffices, warehouses, wholesale stores, etc. The tunnels were commenced in September, 1901, and were originally intended to carry the cables for the automatic telephone system of the Illinois Telephone Company, as it was found that the streets were so completely occupied by water and gas mains, sewers, electrical conduits, and the various manholes, that there was no room to be found for conduits to accommodate cables for the proposed central exchange for 100.-000 subscribers. It was finally determined, therefore, to build a system of tunnels, and to build these deep enough to be within the solid clay, and avoid disturbance of foundations. The city also required them to be deep enough to allow of the future construction of a subway system for street cars, and the level of the tunnel floor is about 30 feet below the street level. After a considerable amount of work had been done the company obtained permission from the city to utilize the tunnels for the transportation of mails, express matter and freight, etc., but their use for passenger traffic is specifically forbidden. In June, 1905, there were about 30 miles completed, and the entire system will aggregate about 60 or 70 miles.

The tunnels are of horseshoe section, with a clear height of 7 feet 6 inches, and a width of 6 feet; they are lined with concrete, having a thickness of 10 inches in the sides and crown and 13 inches in the floor. They are driven in stiff blue clay, containing very little water, but occasional pockets of gas and of quicksand were encountered. As a precaution the work was all done on the pneumatic system, the air pressure being about 9 pounds per square inch. The air locks were placed near the

bottoms of the several shafts; they were 23 feet long, and had doors 24 x 36 inches. No tunneling shields were used. The material was excavated with spades and draw-knives, and hauled away in small cars, 20 x 48 inches inside measurement, to the shafts. These small cars were used to facilitate handling, and to enable a double track of narrow gage (14 inches) to be laid. The shafts were sunk mainly in the basements of buildings, which were utilized also for the making of concrete and storing of cars. In some cases, however, the shafts were located in the streets (at the curb line) and were covered with tall head-houses.

The method of construction was as follows: The excavation was made in the clay for a distance of about 20 feet, and about a foot larger than the completed tunnel. The 13-inch concrete bottom was then put in place, and upon this were placed forms made of 5-inch steel channels in two sections, curved to the contour of the inside of the tunnel, and put together with flanged and bolted joints at top and bottom. These ribs or forms were 3 feet apart, and outside of them were laid 2-inch planks to form the lagging. These planks were at first 20 feet long, but afterwards 15 feet was found more satisfactory. They were laid one at a time on each side and the concrete rammed into the space between them and the clay. When the crown, forming the key, was reached, boards 3 feet long were used. The concrete was composed of 1 part Portland cement, 3 parts sand and 5 parts gravel; it was mixed by machines installed in basements at the heads of the shafts, and carried to the work in the small cars on a double track of 14-inch gage. The concrete was well tamped so as to fill all voids and prevent any subsequent movement in the mass of clay.

The work was carried on continuously in three 8-hour shifts. The mining gang (about 7 men) worked from 4 p. m. to midnight; this was followed by the trimming gang (also about 7 men), which worked until 8 a. m. in trimming the excavation to proper form and dimensions and putting up the centers and lagging. The concreting gang then commenced its work, arranging it so as to complete it in time to make way for the

mining gang at 4 p. m. Work was carried on at about 14 headings, with 20 men to each. The first 12 miles were built in $10\frac{1}{2}$ months, with an average advance of 20 to 76 feet per working day at the different headings. In April and May, 1905, the progress made was 10,105 feet (25 working days) and 12,619 feet (27 working days) respectively; or an average of 404 to 467 feet per working day. This required the excavation of about 60,000 cubic yards of material.

The excavated material was at first carried up the shafts and dumped into wagons, this work being done only at night. When one of the tunnels approached the east side of the river an incline was built, up which the cars were taken by traveling chains having arms to engage the axles, and the cars were dumped into scows. Another incline was built on the lake front, where cars were taken out by electric locomotives and dumped to fill in the site for Grant Park. After this latter method of disposal had been put into service, nearly all the tunnel material was hauled out at the lake front, as well as wreckage from old buildings and the material excavated for deep foundations and basements of new buildings.

The tunnel intersections above mentioned are very peculiar. The two lines intersecting at right angles and on the same level are in most cases connected by four curves of 20-foot radius, leaving four "pillars" of the original ground. Here the roof is reinforced by steel I-beams. The sharpest curves in the main tunnels are of 16-foot radius. The lines are mainly level, with maximum grades of 1.75%, and inclines not exceeding 12%. Branches or spurs are run to the postoffices, stations, etc., to be served, and either enter a deep sub-basement or have a shaft and elevator to the buildings with shallow foundations.

The completed tunnels have a single track of 24-inch gage, laid with 56-pound rails on cast-iron chairs imbedded in the concrete floor. Both the overhead trolley wire and central third-rail conductor system of electric traction have been tried. In the latter case, the Morgan system is used, in which the conductor is a slotted bar protected by side timbers and gearing with a contact or spur wheel on the locomotive. The tunnels

are well drained, lighted by electricity, and provided with telephones at frequent intervals.

It is expected that this system of transporting mails, newspapers, parcels, coal, freight, etc., as well as wreckage from dismantled buildings and material for new buildings, will not only facilitate traffic, but also relieve the congestion of traffic in the busy streets and avoid much of the dirt and nuisance incident to the hauling of refuse and building material through the streets.

Tunneling through soft material in the heart of a city where numerous tall and heavy buildings exist, and where many of these buildings have foundations practically on the surface of this material, is a delicate kind of work which was successfully prosecuted in these Chicago tunnels for about five years, with practically no trouble from settlement of the ground. A change from the original plans, by which the tunnels began to be carried under the buildings as well as under the streets, caused trouble, however, and during the spring and summer of 1905 settlements of streets and buildings occurred, with the result that the effect of city tunnel construction upon the foundations of buildings was made the subject of expert investigation. The Commissioner of Public Works appointed a committee of engineers to investigate the cause, and their first report stated that no settlements had occurred where the main tunnels had been built under air pressure, but that they had occurred where connections or spurs had been built without the use of air pressure. A later report recorded specific instances of settlement and showed that a serious problem faced the tunnel company. The main tunnels are built in the Chicago clay and at a depth of about 20 feet from the street surface to the crown of the tunnel; as they are located under the center lines of the streets they are clear of the lines of pressure from the buildings, and are subject only to the pressure due to the overlying material. At street intersections the tunnels also have intersections, and the two lines of straight tunnel are in many cases connected by four curved tunnels, as already explained. This, of course, involves the removal of a great mass of material, and unless the work is

prosecuted very carefully there is liable to be a slip or movement of the clay. The construction of one of these intersections without sufficient care and precaution is given as the cause of one of the street settlements already referred to.

But a much more serious matter is that of tunneling through clay subjected to pressure from neighboring buildings. As long as the tunnels were to be used simply as conduits for electric wires and cables, there would be very little of this class of work, but when their use for transportation purposes was planned it was proposed to build lateral branches and spurs to serve post-offices, newspapers and express offices, railway passenger and freight stations, wholesale and retail stores, warehouses, office buildings, etc. These spurs would enter the basements of modern buildings having deep basements, while in other cases they would connect with shafts having elevators to serve the building above. The construction of these connections must involve the excavation of clay under varying degrees of pressure from the buildings, and when any void is left, however small and if only temporary, the clay will fill in and the movement of the clay body may extend for considerable distances. The engineering committee considered that the tunnel company had undertaken the construction of these branches without having given sufficient consideration to the special conditions affecting this phase of its work, and recommended that no more such branches should be built until the special conditions in each particular case had been carefully studied and a proper course of construction planned. Whatever care is taken, however, some settlement is considered unavoidable. The use of compressed air will not suffice to sustain the material, and in fact its use in this part of the work was not considered practicable by the committee. The soil under pressure must be supported by mechanical means, and it was pointed out in the report that the case "is a building proposition, and the methods common in building practice will probably meet all the difficulties that may be encountered." The committee also recommended the adoption of a circular section for the spurs and branches instead of the horseshoe section of the main tunnels.

The work was all planned by Mr. George W. Jackson, Chief Engineer and General Manager of the Illinois Tunnel Construction Company, and has been executed by day labor under his direct supervision.

APPENDIX

GLOSSARY OF SOME OF THE MORE UNUSUAL TERMS USED IN TUNNELING

ADIT.—See Heading.

AIR-LOCK.—A device employed in connection with the use of compressed air, for permitting men and material to pass from the normal atmospheric pressure to a higher pressure, or the reverse, without undue loss of pressure in the working-chamber.

AIR-SHAFT.—In mining, a shaft used solely for ventilating purposes.

ALIGNMENT.—The laying-out of the axis of a tunnel by instrumental work. See Ranging.

ARCH-BLOCKS.—A term applied to the wooden voussoirs used in framing a timber support for the tunnel roof, when driving a tunnel on the co-called American system. These blocks are made of plank, superimposed in three or more layers and breaking joint.

BACKING.—The rough masonry in a wall faced with a better class of work.

BACK-JOINT.—A joint-plane more or less parallel to the strike of the rock-cleavage; frequently vertical.

BALLISTIC EFFECT.—The throwing of rock to a distance from the exploded charge, a thing to be avoided in rock-blasting.

BARS.—Strong timbers placed horizontally for supporting the poling-boards in the face of the excavation.

BATTERY.—A magneto-electric apparatus employed in firing an explosive connected with it by a pair of insulated copper wires.

BEARERS.—In shaft-sinking, heavy sticks of timber, longer than the width of the shaft, set in niches cut in the rock, and used as supports for timber-sets.

BEARING-IN SHOTS.—Bore-holes tending to meet in the body of the rock; intended to "unkey" the face when charged and fired.

BENCH.—In tunnel excavation, where a top-heading is driven, the bench is the mass of rock left, extending from about the spring-line to the bottom of the tunnel.

BENCH-MARK.—A permanent mark of a suitable character for preserving and transferring vertical elevations in a tunnel.

BIT.—A piece of steel welded to the end of a drill, or the point of a pick. The horizontal section of this cutting edge is either + or ×-shaped; the edges making an angle of nearly 90°.

BLOCK-HOLING.—The operation of drilling and blasting a detached boulder or mass of rock; the purpose being to reduce the mass to dimensions more easily handled or transported, or cut for building purposes.

BOWK.—An English term for an iron tub used in hoisting debris from a shaft.

BREAKERS.—The row of drill-holes above the mining holes in a tunnel face.

BREAST-BOARD.—The timbers or boards placed horizontally across the face of an excavation, or heading, to prevent the inflow of gravel or other loose or flowing material.

BROB.—An English term for a wrought-iron spike driven into bars and sills to steady the head or foot of a prop.

BULKHEADS.—Masonry diaphragms built across a subaqueous tunnel where compressed air is used, as a precaution and to prevent the flooding of an entire tunnel in case of an accident. These bulkheads are usually kept some distance in the rear of the working face, and are provided with two air-locks; one of them is an emergency-lock near the roof.

BULL.—An iron rod used in ramming clay to line a shot-hole.

BULLING.—Lining a shot-hole with clay.

BURDEN.—In blasting, the volume of rock that should be broken by a proper charge of powder.

CAGE.—The elevator used in a shaft for hoisting the cars loaded with muck. The cage is generally provided with a safety device intended to hold the cage and its load in the case of a breaking hoisting-rope.

CENTERS.—Framed supports, usually arch-shaped, upon which are placed the lagging-boards used, in building an arch, for supporting the roof of a tunnel.

CHAMBER-BLASTING.—Used in very heavy blasting, where a great quantity of rock is to be thrown down at one time by a correspondingly large charge. A tunnel or drift is usually run to the site of the chamber, and the latter is excavated and charged. The drift is well packed with earth and sand before firing. In such a chamber or series of chambers as much as 7,000 lbs. of dynamite may be placed, throwing down 350,000 tons of rock at one blast.

CHAMBERING.—The enlargement of the bottom of a deep drill-hole by the successive explosion of small charges. The purpose is to provide room for a final, large charge of powder to be used in throwing down a large mass of material.

CHOG.—English term for chocks, or blocks spiked into the corner of a shaft to form a bearing for the side-waling piece, or the blocks used in headings to separate the cap and poling-board.

CHURN-DRILL.—A long iron bar with a steel cutting-edge, used in quarrying or in blasting hard-pan, etc. It is worked by lifting and letting it fall.

COLLAR.—The bar, or cross-piece, in a framed timber set. The first wood frame in a shaft.

COLUMN or BAR.—This is a round column set vertically or horizontally in a heading and to it the machine-drill is clamped. This column is provided with a head at one end, and a shoe at the other end provided with a screw for setting it up against the rock walls. A column gives a firmer support, as a rule, than the tripod also used for holding the drill. Blocks of tough wood are placed between the column ends and the rock.

CORE.—In several European methods of tunneling, the sidewalls are built first in special drifts; and the arch area is then excavated and the arch built, leaving the central mass to be removed last. This center of rock or earth is called the "core."

CRATER.—In blasting, the funnel of rupture, which in bad rock may have very steep sides and a relatively small volume of broken rock.

CRIBBING.—Close timbering in lining a shaft. A structure made of horizontal timbers laid one on top of the other.

CRIMPER.—A tool specially made for fastening a cap to a fuse.

CROW-FOOT.—A V-shaped notch in an arch-block; sometimes made in the bottom block where this rests upon the wall-plate.

CROWN-BARS.—Strong timbers, usually round, used in supporting the roof of a tunnel in the English method of driving.

DOG.—A round iron rod, with the pointed ends bent at right angles.

DOLLY.—A tool used to sharpen drills.

DOWELS.—Round, headless iron pins, inserted half way into each of two abutting timbers to prevent slipping.

DRAG-TWIST.—A spiral hook used for wiping a blast-hole with hay before charging with black powder.

DRAWING.—Removing or pulling out the crown-bars in a tunnel.

DRIFT.—See Heading.
DRIFT-FRAME.—See Square Sets.
DUMP.—The place of deposit of debris from an excavation.
ELECTRIC FUSE.—A metallic cup, usually containing fulminating mercury, in which are fixed two insulated conducting wires held by a plug, the latter holding the ends of the wires near to but not touching each other. At this plug is a small amount of a sensitive priming. When an electric current is sent from the battery through these conductors, the resulting spark fires the priming, then the fulminate and the charge of the explosive proper.
ENLARGING SHOTS.—Bore-holes driven after the face of the rock has been "unkeyed," and two or three free-faces have thus been provided.
FACE.—The surface exposed by excavation. The "working-face" is the face at the end of a heading, or the end of a full-size tunnel excavation.
FALSE SET.—A temporary set of timbers, used until the work is sufficiently advanced to put the permanent set in place.
FAULT.—A dislocation in the natural strata.
FLOAT.—This is a timber platform, faced with boiler-iron on both sides and provided with rings at the corners for lifting. It is used in shaft-work to prevent the crushing of the bottom timbers by flying fragments of rock.
FOOT BLOCKS.—Flat pieces of wood placed under props, to give a broader base and distribute the weight.
FOREPOLING.—The act of driving the poling-boards beyond the last set of timbers, thus forming a roof for further advance.
FREEZING-PROCESS.—A method invented by F. A. Poetsch about 1883, for penetrating a water-bearing stratum. Circulating pipes are sunk around the site of a shaft; and the ground and water is then frozen solid by passing through these pipes a solution of brine. The frozen material is then excavated and the shaft lined in the usual manner.
FUSE-CAP.—A small cylinder of copper, closed at one end and charged with a fulminate. The end of the fuse is inserted in this cap, for firing a charge.
GAD.—A small steel wedge used for loosening seamy rock.
GALLERY.—A drift or adit. In France it is another name for the heading of a tunnel, usually called "Advanced Gallery."
GALLOWS-FRAME.—The frame supporting the pulley at the head of a shaft, over which pulley the hoisting-rope runs.
GANISTER.—A hard, compact, exceedingly silicious fire-clay.
GRAIN.—As applied to rock, planes of cleavage at right angles to the rift, or bed of the rock.
GUN.—A term applied to the explosion of a charge in a bore-hole, which simply enlarges the hole without rending or splitting the rock.
GUSSET.—A V-shaped cut in the face of a heading.
HANG-FIRE.—A term applied to a charge which is delayed in exploding, but does eventually explode.
HEAD.—As applied to rock, natural planes of cleavage at right angles to the grain and the rift of the rock.
HEAD-HOUSE.—A covered timber framing at the top of a shaft, into which the shaft-guides are continued that carry the cage or elevator. The term is sometimes applied to the structure containing the hoisting engine, boilers and other machinery, in addition to the actual hoisting-cage, etc.
HEADING.—A smaller excavation driven in advance of the full-size section; it may also be driven laterally, and is then called a "Cross Heading" or "Side Drift." A heading may be driven at the top or the bottom of the full-size face; it is then a "Top" or a "Bottom Heading," as the case may be.
HEAD-PILES.—The top poling-boards in a heading.
HEAD-TREE.—The cap-piece of a heading-set.

Heel-of-a-shot.—In blasting, the face of a shot farthest away from the charge.

Hitch.—A step cut in the side of a shaft, or in other excavations, for holding timbers for various purposes.

Holing-through.—Connecting two sections of a tunnel driven toward each other.

Horse-head.—English term for a heading-frame, of a cap and two posts.

Invert.—A flat inverted arch of masonry used for the floor of the tunnel lining.

Jumper.—A long iron drill, with a steel cutting-edge, worked by blows from a heavy hammer.

Key.—Of an arch; the top closing-voussoir, or ring-stone. The "Key" may also be a closing section of brick masonry.

Kicking-pieces.—Short struts to prevent a sill or other member from being pushed out of place.

Lagging.—Narrow boards, generally planed, placed horizontally on the arch-frames of a center. On this lagging the arch of masonry is built. The term is also applied to poling-boards.

Lead-wires.—Two insulated copper wires leading from the battery or igniting apparatus to the primer-cartridge in an explosive charge. These are also called "Connecting Wires."

Line of Least Resistance.—As this term is used in blasting operations, it indicates the shortest line that can be drawn from the charge in the bore-hole to the outer face of the rock.

Lining.—The lining of a tunnel may be stone, brick or concrete masonry, iron or steel rings, or concrete-steel. In the early American tunnels wood was also used for this purpose.

Loop Tunnel.—A method of gaining grade in a tunnel location by looping or folding the line back upon itself.

Miners.—The row of drill-holes in a tunnel face, located below the breaking-down holes.

Miss-fire.—A term applied to a charge which from some cause has failed to explode.

Mop.—A disc of some material used around a drill, to prevent water from splashing up.

Muck.—The broken rock or other material coming from a tunnel excavation.

Mud-capping.—A method of breaking up boulders by placing dynamite on top of the boulder and covering this with wet clay. The process is very wasteful of powder, as the powder does not do its best work.

Needles.—An English term used for a special form of poling-boards; they are sometimes made of iron or steel plate and may be as much as 10 feet long by 6 inches wide.

Nipper.—A name given to the boy who carries the drills to the smithshop.

Out-croppings.—Applied to a rock or ore-vein as seen exposed on the surface.

Overwinding.—A term applied to a continued pull on the hoisting rope of a cage, after the cage has reached the top of the shaft. The result of this carelessness, or accident, is a broken hoisting rope and all the danger that implies.

Packing.—Any material, usually rock, packed between the rock-roof of a tunnel and the top of the arch-masonry.

Pigeon-hole.—An opening left at the meeting of two sections of arch work, permitting the workmen to close the arch and to come out. The "Pigeon-hole" itself is closed from below.

Pilot-tunnel.—See detailed description in text.

Plant.—A term used to include the machinery, derricks, railway, cars, etc., employed in tunnel work.

Plug-and-feather Hole.—A hole drilled for the purpose of splitting a block of stone. These holes are usually in rows. The plug is a slightly

wedge-shaped piece of iron driven between two L-shaped irons, or "feathers," inserted in the hole.

PLUGS.—Small wooden pins driven into holes driven in the rock-roof of a tunnel. The axis of the tunnel is marked on these plugs by tacks, or by small iron hooks from which a plummet-lamp may be suspended for sighting upon.

PLUMB-POSTS.—The vertical posts at the side of a tunnel, resting on sills and carrying the wall-plates; the whole supporting the tunnel roof by means of centering.

POLING-BOARDS.—Narrow boards of varying lengths, sharpened at the front end and driven forward over the bars to support the roof or sides of a heading or of a full arch section.

POP-SHOT.—In blasting, when the explosion of the charge simply blows out the tamping.

PORTALS.—The entrance and exit of a finished tunnel, usually faced by masonry to support the loose rock or earth.

PRIMER-CARTRIDGE.—The cartridge to which the cap and fuse are attached, or, in electric firing, into which the electric cap is inserted.

PROPS.—Struts or posts, either vertical or raking, used as supports or stays in tunnel timbering. The inclined prop is usually called a "Raker."

PUNCHEONS.—English term for the props, or posts set up between lines of waling in shaft-sinking. See Studdle.

RAKER.—See Props.

RANGING.—The English term for aligning a tunnel.

RIFLED.—A term applied to the three-cornered section of a hole drilled by hand. Though the bit is supposed to be turned one-eighth after each blow, to insure a circular hole, the majority of hand-drilled holes are three-cornered.

RIFT.—In sedimentary rocks, the horizontal plane of stratification, or the bed of the rock.

RUN.—The escape of any flowing material into the tunnel-area; it may be sand, gravel, or mud.

RUNNERS.—English term for sheet-piling.

SAFETY FUSE.—The safety or time fuse is made of a core of meal-powder lightly compressed and enclosed in one or more wrappers of spun-yarn made waterproof. According to the number of wrappers and the dampness of the ground in which they are to be used, fuses are called "Single Tape," "Double Tape," etc.

SCRAG.—The batir of a post.

SERIES SHOTS.—A number of loaded holes connected and fired one after the other. In contradistinction to "Simultaneous Firing," where the charges are connected electrically, and are all exploded at one time.

SETTINGS.—The timber frames used at intervals in shaft-sinking, and close-poled behind.

SHAFT.—Temporary or permanent pits sunk to give access to an underground working. The shaft may be vertical or inclined, though the latter is only used in mining operations.

SHIELD.—A metal diaphragm used in tunneling under rivers, or in water-bearing or loose material under cities. The shield may be cylindrical and include the entire tunnel section; or it may be a "Roof-shield" and support the roof only.

SHIFT.—The working hours per day of a gang of laborers.

SIDE-PILES.—Another term for the side poling-boards in driving a heading

SIDE-TREES.—The two posts of a heading-set.

SILLS.—Strong timbers laid horizontally to support posts or other tunnel timbers.

SKIPS.—Metal buckets, usually opening at the bottom; sometimes used for removing water from shafts.

SLIP.—A fault. A smooth joint where one stratum has moved on another.

SOCKET.—The bottom of a shot-hole, not blown away in firing.

Soldier-frame.—Frames set into the inside of a shaft prior to breaking through for a heading.

Sole-plate.—Formed of several pieces of lagging fastened together, and laid down in the bottom of an invert. It forms a base for the iron ribs used in laying a concrete invert.

Spiral Tunnel.—A method of gaining grades in a tunnel by driving the tunnel on a constantly ascending and circular line.

Spoon.—A scraper, or similar instrument, for cleaning the sludge out of shallow drill-holes. This spoon is usually made of one-fourth to one-half inch iron rod, with a disc at each end.

Sprag.—The horizontal member of a square set of timbers running parallel to the axis of a heading.

Springing a Hole.—Enlarging a drill-hole at the bottom to permit the use of a greater charge of explosive. This is usually done by exploding smaller charges of dynamite at the bottom of the hole and thus pulverizing the harder rock. The process is also called "chambering," "shaking," and "bullying."

Springing-line.—The horizontal line drawn at the point of origin of an arch; or at the point where the intrados of the arch meets the interior face of the side-walls or abutments.

Square Sets.—Timber frames used at intervals to support poling-boards, in shaft-sinking or driving a heading.

Stations.—Points on the center-line of a tunnel, permanently marked. These stations may be outside of the tunnel and used for projecting the center-line into the tunnel, or they may mark the center-line inside the tunnel.

Stone-boat.—A species of wooden sled, used for hauling large stones a comparatively short distance.

Stretchers.—In shaft-sinking, the cross-pieces holding the waling apart.

Striking.—Lowering the arch-centers, after the masonry is completed and the mortar set.

Striking-plates.—Two horizontal timbers separated by striking-wedges and supporting an arch-center. The latter is lowered by slacking the wedges.

Stripping.—Removing the earth, etc., overlying rock that is to be excavated. English miners apply the term of "over-burden" to this same overlying material.

Studdle.—A square timber, or short post, placed vertically between two sets of shaft timbers.

Stump-prop.—Short posts set under the crown-bars of a tunnel.

Sump.—An excavation, usually at the bottom of a shaft, to collect water so that it may be better handled by the pumps or buckets.

Tailing.—Giving the proper angle, or elevation, in driving the poling-boards in a heading.

Tamping.—The material placed over a charge in a bore-hole, to better confine the force of the explosion to the lower part of the hole.

Tending Chuck.—Pouring water into a drill-hole to assist in drilling.

Template.—A form for building tunnel inverts.

Timbering.—A general term for the placing of timber, to support the roof or the face of a tunnel during excavation and lining.

Toothing.—In a stone or brick arch, the jogs left in the face of the arch-work, for the purpose of joining it to the following section.

Trimmers.—The top row of holes in a tunnel face.

Tucking Space.—The space between the blocks separating the cap in a heading-set from the poling driven. This space provides for driving the second set of poling-boards.

Unkeying.—In attacking a rock-face the first effort of the miner is directed toward making a cut that will permit the succeeding shots to exert the greatest force with the minimum charge of explosive. In do-

ing this "unkeying," he takes advantage of any persistent seam in the rock face.

WALINGS.—Sets of longitudinal timbers used as guides in driving sheet piling, etc. Also the horizontal side-pieces in a shaft-set separated by "stretchers."

WALL-PLATE.—A horizontal timber supported by posts resting on "sills" and extending lengthwise on each side of the tunnel. On these wall-plates the roof-supports rest.

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